ADA

ALTERNATIVE FUELS COMPATIBILITY WITH ARMY EQUIPMENT TESTING – ALTERNATIVE FUELS MATERIAL COMPATIBILITY ANALYSIS

INTERIM REPORT
TFLRF No. 423

by
Shayla L. O'Brien
Scott A. Hutzler

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD15)

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Gary Bessee

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14. ABSTRACT

Many of the materials used for tactical fuel handling equipment were designed for use with petroleum-derived fuels, such as diesel and JP-8. However, emerging synthetic turbine fuels based on iso-paraffinic kerosene (IPK), synthetic paraffinic kerosene (SPK), and Hydroprocessed Esters and Fatty Acids (HEFA) have undergone extensive testing and gained approval for use by the Air Force. As these fuels become more widely available and their use extends to ground vehicles and support equipment, their impact on current Army equipment will need to be assessed. The overall aim of this effort was to execute material compatibility testing to support the evaluation of emerging synthetic alternative fuels.

15. SUBJECT TERMS

Material compatibility, HEFA, Fischer Tropsch, IPK, SPK, jet fuel, diesel, Fluorosilicone, nitrile, fluorocarbon, PTFE, O-rings

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EXECUTIVE SUMMARY

The overall aim of this effort was to execute material compatibility testing to support the evaluation of emerging synthetic alternative fuels. This report contains information on the following materials: fluorosilicone, nitrile, polyurethane, Viton®® and Teflon®®. These materials were selected by researching Army technical manuals. The report also contains information on the following alternative fuels: Sasol IPK, R-8 HRJ SPK, Camelina HRJ SPK, Tallow HRJ SPK and Rentech HRJ SPK. The material compatibility of the selected materials were tested against 50/50 blends of the alternative fuels with Jet A additized to JP-8.

The material compatibility evaluation followed ASTM standards which covered the following tests: change in volume, change in thickness, change in Shore M hardness, tensile strength and compression set. Static soak tests were conducted at 40 °C and 60 °C using a four week immersion period. Fuel switch loading tests were conducted using an eight week immersion period.

The results showed that there are some minor property changes between the baseline fuels and the 50/50 alternative blends. The differences observed do not appear sufficiently significant to cause any issues with the tactical fueling systems, but it is recommended that a chosen alternative fuel blend be tested with the hardware.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute® (SwRI®), San Antonio, Texas, performed this work during the period December 2010 through February 2012 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSRD-TAR-D/MS110) served as the TARDEC contracting officer's technical representative. Mr. Eric Sattler of TARDEC served as project technical monitor.

The author would like to acknowledge the contribution of the TFLRF technical support staff along with the administrative and report-processing support provided by the TFLRF administrative staff.

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ACRONYMS AND ABBREVIATIONS

AAFARS	Advanced Aviation Forward Area Refueling System
AFARE	Artic Forward Area Refueling Equipment
AFRL	Air Force Research Laboratory
ASTM	American Society for Testing and Materials
°C	Celsius
DiEGME	Diethylene Glycol Monomethyl Ether
EPDM	Ethylene Propylene Diene Monomer
FARE	Forward Area Refueling Equipment
FARP	Forward Area Refueling Point
FSSP	Fuel System, Supply Point
FT	Fischer Tropsch
HEFA	Hydroprocessed Esters and Fatty Acids
HTARS	HEMTT Tanker Aircraft Refueling System
IPDS	Inland Petroleum Distribution System
IPK	Iso-Paraffinic Kerosene
KOH	potassium hydroxide
mg	milligram
mL	milliliter
NSN	National Stock Numbers
PTFE	Polytetrafluoroethylene
SPK	Synthetic Paraffinic Kerosene
TFE	Tetrafluoroethylene
ULSD	Ultra Low Sulfur Diesel

1.0 BACKGROUND

Many of the materials used for tactical fuel handling equipment were designed for use with petroleum-derived fuels, such as diesel and JP-8. Diesel can contain up to 35% aromatics and JP-8 typically contains 15-20% aromatics. However, emerging synthetic turbine fuels based on iso-paraffinic kerosene (IPK), synthetic paraffinic kerosene (SPK), and Hydroprocessed Esters and Fatty Acids (HEFA) typically contain no aromatics. Many of these fuels have undergone extensive testing and gained approval for use by the Air Force. As these fuels become more widely available and their use extends to ground vehicles and support equipment, their impact on current Army equipment will need to be assessed. Research was performed to (1) determine what materials are used in current tactical refueling equipment, (2) identify suitable test protocols, and (3) assess the compatibility of these materials with a variety of new emerging fuels.

2.0 APPROACH

2.1 IDENTIFY TACTICAL REFUELING SYSTEMS

With input from the Army, SwRI identified and down-selected tactical refueling systems to be included in this study. Bulk storage, such as collapsible fuel tanks, and distribution systems, such as IPDS, were not included in this study. A list of equipment within each system was compiled and the related technical manuals and parts lists were obtained. The following refueling systems were selected.

- Forward Area Refueling Equipment (FARE)
- Artic Forward Area Refueling Equipment (AFARE)
- Fuel System Supply Point (FSSP)
- Forward Area Refueling Point (FARP)
- Advanced Aviation Forward Area Refueling System (AAFARS)
- HEMTT Tanker Aviation Refueling System (HTARS)
- Inland Petroleum Distribution System (IPDS)

2.2 Material Selection

Having identified the tactical refueling systems and obtained the necessary technical manuals for equipment therein, SwRI compiled a list of materials for each system. There was commonality among the various systems in the types of materials used. A down-select of materials was made by evaluating the compatibility with diesel, kerosene and JP-8. Since obtaining the actual parts used in the equipment is impractical, the materials were tested in O-ring form.

2.2.1 Identifying Materials

Previous studies have evaluated nitrile in fuels with varying aromatic content as nitrile is most commonly used for seals [1,2]. For this study, O-ring materials were selected by referencing the appropriate Army technical manuals to collect National Stock Numbers (NSN) and their associated material. A spreadsheet was compiled of NSN numbers, the part name to identify the function of the material, and their associated material (Table 1). The NSN numbers were found from manuals that were downloaded using the following two websites:

https://www.logsa.army.mil/etms/index.cfm?fuseaction=viewsearchform&CFID=1425444&CFTOKEN=ec67ba272e9747-BBDD081B-A597-0B56-BDFC8F27F9D7E42B

www.liberatedmanuals.com

No manuals were found helpful for AFARE, AHS or FARP. Once NSN numbers of interest were collected the following website was used to determine the material:

http://www.dlis.dla.mil/webflis/pub/pub_search.aspx

Not all of the NSN numbers came up with useful information but the following list of materials was determined. Teflon®, Butadiene-acrylonitrile class NBR (Buna-N), tetrafluoroethylene (TFE), polyester urethane class AU, polyether urethane class EU, EPDM, Viton®, fluorosilicone class FQ, polytetrafluoroethylene (PTFE), polyolefin and polyester.

Table 1. NSN Numbers with Designated Material

Assembly	Part #/ CAGEC	NSN	Part Name	Material
AAFARS		3040-01-460-3310	Seal, shaft	Material not provided
FSSP	220464 (0DT23)	3120-01-456-3926	Bearing, sleeve	Material not provided
AAFARS	220466 (0DT23)	3120-01-456-3926	Bearing, sleeve	Material not provided
AAFARS		4720-00-540-1368	Hose, nonmetallic	Material not provided
AAFARS		4720-01-218-6958	Hose, preformed	Rubber synthetic
AAFARS		4720-01-515-3130	Hose assembly	Material not provided
AAFARS		4720-01-515-3131	Hose assembly	Material not provided
FSSP	78007-3	4720-01-542-7663	Hose, nonmetallic	Material not provided
FSSP	882357	4720-01-543-3903	Hose, nonmetallic	Teflon®
FSSP	882346	4720-01-543-3906	Hose, nonmetallic	Teflon®
FSSP	78010-1	4720-01-543-5748	Hose, nonmetallic	Material not provided
FSSP	78009-1	4720-01-543-6638	Hose, nonmetallic	Material not provided
FSSP	882359	4720-01-543-7926	Hose, nonmetallic	Teflon®
FSSP	882345	4720-01-543-7930	Hose, nonmetallic	Teflon®
FSSP	882348	4720-01-543-8381	Hose, nonmetallic	Teflon®
FSSP	882347	4720-01-543-8735	Hose, nonmetallic	Teflon®
FSSP	882358	4720-01-543-8739	Hose, nonmetallic	Teflon®
FSSP	882356	4720-01-543-8745	Hose, nonmetallic	Teflon®
FSSP	78007-1	4720-01-544-3261	Hose, nonmetallic	Material not provided
AAFARS	MSS1521B5S	4730-00-241-8349	Elbow, tube	Material not provided
AAFARS	220464 (0DT23)	4730-01-544-3265	Bushing, hose	Material not provided
FSSP	220464 (0DT23)	4730-01-544-3265	Bushing, hose	Material not provided
AAFARS	23893 (0DT23)	4930-01-053-0187	Seal	Material not provided
FSSP	23890	4930-01-053-0189	Retainer, seal	Material not provided
HTARS	23890	4930-01-053-0189	Retainer, seal	Material not provided
HTARS	47058	4930-01-385-9488	Seal assembly, nose	Material not provided
AAFARS	MS29513-010 (96906)	5300-00-004-3096	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-134 (96906)	5320-00-641-0119	O-ring	Butadiene-acrylonitrile class NBR
FARE	AA59326-G8	5330-00-088-9166	Gasket	Butadiene-acrylonitrile class NBR
HTARS	MS27030-8	5330-00-088-9166	gasket	Butadiene-acrylonitrile class NBR
AAFARS	MS27030-8 (96906)	5330-00-088-9166	Gasket	Butadiene-acrylonitrile class NBR
FSSP	MS27030-8 (96906)	5330-00-088-9166	Gasket	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-175 (96906)	5330-00-172-6348	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-157 (96906)	5330-00-182-3170	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	13217E5363 (97403)	5330-00-235-4716	Gasket, Sight Gauge	Rubber synthetic
AAFARS	MS29513-009 (96906)	5330-00-248-3834	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-010 (96906)	5330-00-248-3835	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-014 (96906)	5330-00-248-3840	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-016 (96906)	5330-00-248-3845	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-234 (96906)	5330-00-251-9367	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-227 (96906)	5330-00-260-9338	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29512-03 (96906)	5330-00-263-8011	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-133 (96906)	5330-00-291-7384	O-ring	Butadiene-acrylonitrile class NBR
FSSP	6686-N	5330-00-346-2732	Gasket	Material not provided
FSSP	MS27030-5	5330-00-360-0595	Gasket	Rubber synthetic
AAFARS	MS27030-5 (96906)	5330-00-360-0595	Gasket	Rubber synthetic
IPDS	00-90007	5330-00-412-9780	Gasket	Rubber synthetic

Assembly	Part #/ CAGEC	NSN	Part Name	Material
FSSP	AA59326-G-10	5330-00-412-9780	Gasket	Rubber synthetic
AAFARS	MS29513-141 (96906)	5330-00-527-8555	O-ring	Butadiene-acrylonitrile class NBR
FSSP	AN763-40 (81352)	5330-00-599-5831	Gasket	Material not provided
FARE	AA59326-G6	5330-00-612-2414	Gasket	Rubber synthetic
IPDS	AA59326-G6	5330-00-612-2414	Gasket	Rubber synthetic
AAFARS	MS27030-6 (96906)	5330-00-612-2414	Gasket	Rubber synthetic
FSSP	MS27030-6 (96906)	5330-00-612-2414	Gasket	Rubber synthetic
AAFARS	MS29513-134 (96906)	5330-00-641-0119	O-ring	Butadiene-acrylonitrile class NBR
FSSP	13216E8238 (97403)	5330-00-647-2072	Gasket	Rubber synthetic
AAFARS	MS28774-017 (96906)	5330-00-833-4210	Back-up Ring	tetrafluoroethylene
AAFARS	MS29513-160 (96906)	5330-00-860-2395	O-ring	Butadiene-acrylonitrile class NBR
FARE	AA59326-9	5330-00-899-4509	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
FSSP	AA59326-9	5330-00-899-4509	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
IPDS	AA59326-9	5330-00-899-4509	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
AAFARS	MS27030-9 (96906)	5330-00-899-4509	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
FSSP	MS27030-9 (96906)	5330-00-899-4509	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
FSSP	201201-151	5330-01-053-0217	O-ring	Material not provided
HTARS	201201-151	5330-01-053-0217	O-ring	Material not provided
HTARS	24085	5330-01-053-0221	Gasket	Material not provided
AAFARS	24085 (0DT23)	5330-01-053-0221	Seal	Material not provided
FSSP	24085 (0DT23)	5330-01-053-0221	Gasket	Material not provided
IPDS	MS29513-383	5330-01-067-3449	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	13216E9176 (97403)	5330-01-109-1369	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
FSSP	AA59326-G-1	5330-01-138-2108	Gasket	Butadiene-acrylonitrile class NBR, polyester urethane class AU or polyether urethane class EU
FSSP	MS27194-40 (81343)	5330-01-197-8407	Gasket	Butadiene-acrylonitrile class NBR
FSSP	10231-C (05443)	5330-01-207-8302	Gasket	Material not provided
HTARS	207807	5330-01-247-1080	Seal	Material not provided
AAFARS	207807 (0DT23)	5330-01-247-1080	Seal	Material not provided
FSSP	207807 (0DT23)	5330-01-247-1080	Seal, plain	Material not provided
HTARS		5330-01-247-1080	Seal, plain	Material not provided
FSSP	235RF-02092G (41592)	5330-01-262-1340	Gasket, valve bonnet	Material not provided
IPDS	FCB-62398	5330-01-262-5120	Gasket	Material not provided
HTARS	209029	5330-01-264-0134	Seal, plain	Material not provided
AAFARS	7744814	5330-01-313-7900	Gasket	Material not provided
FSSP	600-0101-10	5330-01-368-3629	Seal, plain	Material not provided
AAFARS	7745108 (62445)	5330-01-393-2897	Gasket	Material not provided
AAFARS	7745059 (62445)	5330-01-393-2902	Gasket, Timing Cover	Material not provided
FSSP	161001	5330-01-395-7688	Gasket	Material not provided

Assembly	Part #/ CAGEC	NSN	Part Name	Material
AAFARS	7745125	5330-01-396-5885	Gasket	Material not provided
AAFARS	7757912 (62445)	5330-01-396-5886	O-ring	Material not provided
AAFARS	7745062 (62445)	5330-01-396-8052	Gasket, Intake Manifold	Material not provided
AAFARS	45124	5330-01-396-8058	Gasket	Material not provided
AAFARS	45076	5330-01-406-7022	Gasket	Material not provided
IPDS	FB7661	5330-01-415-8850	Gasket	Material not provided
FARE	220146	5330-01-433-9203	Seal, plain	Material not provided
AAFARS	220146 (0DT23)	5330-01-433-9203	Seal	Material not provided
FSSP	220146 (0DT23)	5330-01-433-9203	Seal, plain	Material not provided
AAFARS	100F0790 (08915)	5330-01-435-3780	Gasket, Inlet Flange	Material not provided
AAFARS	F6455	5330-01-435-3783	Gasket	Material not provided
AAFARS	1200F6505 (08915)	5330-01-435-3786	Gasket, Rotor Cover	Material not provided
FSSP	5500220 (33813)	5330-01-454-2848	Gasket	rubber
FSSP	220459	5330-01-456-8757	Retainer, seal	Material not provided
AAFARS		5330-01-456-8757	Retainer, seal	Material not provided
FARE	220157	5330-01-456-9662	Seal, plain	Material not provided
AAFARS	220157 (0DT23)	5330-01-456-9662	Seal, Upstream	Material not provided
FSSP	220157 (0DT23)	5330-01-456-9662	Seal, plain	Material not provided
AAFARS	220158 (0DT23)	5330-01-456-9663	Seal, Downstream	Material not provided
FSSP	220158 (0DT23)	5330-01-456-9663	Seal, plain	Material not provided
AAFARS		5330-01-456-9666	Sleeve, seal, coupler	Material not provided
FARE	KD64020-1	5330-01-458-5113	Parts Kit, seals	Material not provided
FSSP	220465	5330-01-458-5461	Seal, plain	Material not provided
AAFARS	220465 (0DT23)	5330-01-458-5461	Seal	Material not provided
FSSP	220465 (0DT23)	5330-01-458-5461	Seal, plain	Material not provided
AAFARS	450R.060 (52845)	5330-01-459-2054	Gasket	Material not provided
AAFARS	7745115 (62445)	5330-01-459-2063	Gasket	Material not provided
AAFARS	220467 (0DT23)	5330-01-460-8998	Seal	Material not provided
FSSP	220467 (0DT23)	5330-01-460-8998	Seal, plain	Material not provided
AAFARS	1029-00 (09PD1)	5330-01-503-4873	Set, gasket	EPDM
AAFARS	1030 (09PD1)	5330-01-503-4883	Carrier, long, retainer, seal	Material not provided
AAFARS	1031 (09PD1)	5330-01-503-4885	Carrier, short, retainer, seal	Material not provided
AAFARS		5330-01-515-4276	Retainer, seal	Material not provided
AAFARS	220778 (0DT23)	5330-01-527-9423	Ring, backup	Material not provided
FSSP	TTMA/C4401 (2P653)	5330-01-543-1161	Gasket	Material not provided
FSSP	102460 (47186)	5330-01-543-4621	Gasket	Material not provided
FARE	221284	5330-01-543-5609	Seal, plain	Material not provided
FSSP	221284 (0DT23)	5330-01-543-5609	Seal, plain	Material not provided
FSSP	102482 (47186)	5330-01-543-5712	Gasket	Viton®
FSSP	881765 (47186)	5330-01-543-7947	Seal, plain	Material not provided
FSSP	LA01527-104 (47674)	5330-01-544-6735	Seal, plain	Material not provided
AAFARS	451R.024 (2X179)	5330-01-571-1086	Gasket	Material not provided
AAFARS	MS29513-008 (96906)	5331-00-248-3833	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-009 (81343)	5331-00-248-3834	O-ring	Butadiene-acrylonitrile class NBR
FARE	22504-10	5331-00-248-3835	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-010 (81343)	5331-00-248-3835	O-ring	Butadiene-acrylonitrile class NBR

Assembly	Part #/ CAGEC	NSN	Part Name	Material
FARE	MS29513-014	5331-00-248-3840	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-014 (81343)	5331-00-248-3840	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-016 (81343)	5331-00-248-3845	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-234 (81343)	5331-00-251-9367	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-227 (96906)	5331-00-260-9338	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29512-03 (81343)	5331-00-263-8011	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-126 (81343)	5331-00-265-1076	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-126 (96906)	5331-00-265-1076	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-125 (96906)	5331-00-265-1089	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-028 (81343)	5331-00-265-1093	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	M25988/1-908 (81349)	5331-00-279-9322	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-240 (81349)	5331-00-279-9351	O-ring	Fluorosilicone class FQ
IPDS	MS29513-250	5331-00-291-3085	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-229 (81343)	5331-00-291-3273	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-229 (96906)	5331-00-291-3273	Quad-Ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-136 (81343)	5331-00-291-7295	O-ring	Butadiene-acrylonitrile class NBR
FARE	MS29513-228	5331-00-291-7337	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-228 (81343)	5331-00-291-7337	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-228 (81343)	5331-00-291-7337	O-ring	Butadiene-acrylonitrile class NBR
FARE	MS29513-133	5331-00-291-7384	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-133 (81343)	5331-00-291-7384	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	M25988/1-018 (81349)	5331-00-328-9131	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-036 (81349)	5331-00-364-9762	O-ring	Fluorosilicone class FQ
FARE	MS29513-032	5331-00-481-9987	O-ring	Butadiene-acrylonitrile class NBR
FSSP	MS29513-032	5331-00-481-9987	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	M25988/1-152 (81349)	5331-00-498-5806	O-ring	Fluorosilicone class FQ
FSSP	MS29513-147 (81343)	5331-00-531-4588	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	MS29513-147 (96906)	5331-00-531-4588	O-ring	Butadiene-acrylonitrile class NBR
AAFARS		5331-00-641-0019	O-ring	Material not provided
FSSP	MS29513-134 (81343)	5331-00-641-0119	O-ring	Butadiene-acrylonitrile class NBR
AAFARS		5331-00-641-1119	O-ring	Rubber synthetic
AAFARS	M25988/1-017 (81349)	5331-00-759-2121	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-134 (81349)	5331-01-007-1600	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-235 (81349)	5331-01-007-4899	O-ring	Fluorosilicone class FQ
FSSP	M25988/1-235 (81349)	5331-01-007-4899	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-145 (81349)	5331-01-010-2419	O-ring	Fluorosilicone class FQ
AAFARS	M25988/1-040 (81349)	5331-01-244-2274	O-ring	Fluorosilicone class FQ
FSSP	M25988/1-040 (81349)	5331-01-244-2274	O-ring	Fluorosilicone class FQ
AAFARS	207792 (0DT23)	5331-01-246-7351	O-ring	Material not provided
FSSP	M29512-03 (81343)	5331-01-263-8011	O-ring	Material not provided
AAFARS	M25988/1-171 (81349)	5331-01-281-6513	O-ring	Fluorosilicone class FQ
IPDS	MS29513-250CP	5331-01-324-5262	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	57901	5331-01-393-2899	O-ring	Material not provided
AAFARS	57978	5331-01-393-2900	O-ring	Material not provided
FSSP	151002 (47186)	5331-01-395-7686	O-ring	Material not provided
FSSP	151010 (47186)	5331-01-395-7687	O-ring	Material not provided
AAFARS	A21R.025 (52845)	5331-01-396-5884	O-ring	Material not provided
AAFARS	57949	5331-01-396-8060	O-ring	Material not provided

Assembly	Part #/ CAGEC	NSN	Part Name	Material
AAFARS	M25988/1-172 (81349)	5331-01-424-0680	O-ring	Fluorosilicone class FQ
AAFARS	000U-Z015-14 (51744)	5331-01-458-5559	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	M83461/1-207 (81349)	5331-01-458-5562	O-ring	Butadiene-acrylonitrile class NBR
AAFARS	Q04188 (76700)	5331-01-459-2046	O-ring	Material not provided
AAFARS	ED0079R0790-S (52845)	5331-01-459-2050	O-ring	Material not provided
AAFARS	220779 (0DT23)	5331-01-527-9424	Seal, Teflon®	Polytetrafluoroethylene
AAFARS	220724-007 (0DT23)	5331-01-543-5080	O-ring	Material not provided
FSSP	220724-007 (0DT23)	5331-01-543-5080	O-ring	Material not provided
FSSP	101490 (47186)	5331-01-543-7885	O-ring	Material not provided
FSSP	103409 (47186)	5331-01-543-7984	O-ring	Viton®
FSSP	101337	5331-01-543-9548	O-ring	Material not provided
FSSP	102480 (47186)	5331-01-543-9637	O-ring	Material not provided
FSSP	C254 (70847)	5340-00-244-7325	Seal	Material not provided
FARE		5340-00-244-7325	Seals	Material not provided
FSSP	C256 (70847)	5340-00-244-7327	Seal	Material not provided
FARE		5340-00-244-7327	Seals	Material not provided
FSSP	A01135-000	5340-01-543-3963	Seal	Material not provided
HTARS	24059	5365-01-053-0186	Spacer, seal	Material not provided
AAFARS	7745067 (62445)	5365-01-406-6401	Gasket	Material not provided
AAFARS	220083-1 (0DT23)	5365-01-527-9426	Seal, Sleeve	Material not provided
AAFARS	7767447	5945-01-450-2765	Gasket	Material not provided
AAFARS	M23053/4-303-0	5970-01-142-2282	Sleeving	Polyolefin
AAFARS	M23053/18-106-C	5970-01-359-7837	Insulation Sleeving	Fluoropolymer
AAFARS	GRP-120-1/2BLK	5970-01-362-4196	Sleeving	Polyester
AAFARS		9150-00-119-9291	Compound, Silicone (81349) MIL-G-4343	Material not provided
AAFARS	1320E5909 (97403)		O-ring	Material not provided
AAFARS	220083-1 (0DT23)		Seal, Sleeve	Material not provided
AAFARS	220094-1 (0DT23)		Seal, Wiper	Material not provided
AAFARS	220724-007 (0DT23)		O-ring	Material not provided
AAFARS	220779 (0DT23)		Seal, Teflon®	Material not provided
AAFARS	415MC-212-GC (0DT23)		Seal	Material not provided
AAFARS	4CSBXSS		Elbow, tube	Material not provided
AAFARS	532574-01 (63631)		O-ring	Material not provided
AAFARS	7745076 (62445)		Gasket, Fuel pump	Material not provided
AAFARS	7745122 (62445)		Gasket, Pan	Material not provided
AAFARS	7745124 (62445)		Gasket, Exhaust Manifold	Material not provided
AAFARS	7745131 (62445)		Gasket	Material not provided
AAFARS	7745173 (62445)		Gasket, Cylinder	Material not provided
AAFARS	7757901 (62445)		O-ring	Material not provided
AAFARS	7757949 (62445)		O-ring	Material not provided
AAFARS	7757978 (62445)		O-ring	Material not provided
AAFARS	7757979 (62445)		O-ring	Material not provided
AAFARS	MS29513-028 (96906)		O-ring	Material not provided
AAFARS	MS29513-228 (96906)		O-ring	Material not provided

2.2.2 Material Compatibility Selection

A material compatibility list was put together using the materials determined from the manuals. The materials were evaluated for their compatibility with JP-8, diesel and kerosene. The idea being that if the material is not compatible with the baseline fuels then there was no need to test them against the alternative fuels. The sources used to put together this table were from the Parker O-ring handbook, Cole Parmer Compatibility Tables, Spectrum labs and Dow. Table 2 shows the findings.

EPDM, polyolefin and polyester were found in the Army manuals, but were not included in this test plan due to their poor compatibility with JP-8, diesel and/or kerosene. They also were not selected because there were few instances of their use in the NSN part list (Table 1). The compatibility for TFE was not found, but since it is similar to PTFE and there were more instances of PTFE being used, TFE was not included in this study.

Table 2. Material Compatibility with Selected Fuels

Material	JP-8	Kerosene	Diesel
Teflon® / PTFE	Excellent	Excellent	Excellent
Buna N	Excellent	Excellent	Excellent
TFE	Unknown	Excellent	Excellent
Polyurethane AU	Excellent	Excellent	Fair
Polyurethane EU	Excellent	Excellent	Fair
EPDM	Severe Effect	Severe Effect	Severe Effect
Fluorocarbon FKM	Excellent	Excellent	Excellent
Fluorosilicone FQ	Good	Excellent	Excellent
Polyolefin			Fair
Polyester		Fair	

2.2.3 O-ring Samples

The Parker O-ring guide [3] was referenced in order to determine O-ring part numbers that conform to military specifications. It was not possible to obtain Parker polyurethane O-rings in a reasonable amount of time, so instead Dichtomatik O-rings were ordered. It is an equivalent replacement, in that they are both 70 durometer polyurethane O-rings. The materials that were ordered are listed in Table 3 with the Parker O-ring part number, the military specification to which it conforms (when applicable), and the supplier.

Table 3. O-ring Samples Used During Test

Material	Parker part #	Military Specification	Supplier
PTFE/ Teflon®®	N/A	N/A	Performance Seals
Buna Nitrile	N0674-70	MIL-G-21569B, Class I	Performance Seals
Polyurethane	N/A	N/A	Darcoid
Fluorocarbon FKM / Viton®®	V1164-75	MIL-R-83248C, Type I, Class I	Texas Seal Supply
Fluorosilicone FQ	L1120-70	MIL-R-25988, Type I, Class I	Performance Seals

2.3 TESTING PROTOCOLS

2.3.1 Test Methods

ASTM standards were followed for this study. The standards are referenced by their method numbers throughout this document, e.g., “D1414.” The tests that were run are described in more detail below.

ASTM D395	Standard Test Methods for Rubber Property – Compression Set
ASTM D471	Standard Test Method for Rubber Property – Effect of Liquids
ASTM D1414	Standard Test Methods for Rubber O-rings
ASTM D2240	Standard Test Method for Rubber Property – Durometer Hardness

2.3.2 Tests Performed Throughout Study

O-ring testing typically consists of two parts – 1) aging of the O-ring, and 2) subsequent testing of the O-ring including baseline measurements. The aging portion may include several factors such as soak treatment, static/dynamic aging, switch-loading, compression set testing, temperature cycling, and test length. The testing portion of the analysis may include such tests as dimensional changes, durometer hardness, tensile load/strength, volume/mass change, and changes in appearance.

The following sections describe in more detail the tests that were performed and what method was utilized. These tests are used to evaluate the ability of rubber to withstand exposure to various liquids, including all fuel types selected for this study. These are common tests widely used in industry to gauge material compatibility and robustness. As such, these test methods should be applicable to any hydrocarbon-based fuel.

2.3.2.1 Change in Volume

The change in volume relates to whether or not a good seal will form. The change in volume was determined using a modified version of D471 [4]. The modification was to the immersion specimen set-up. The O-rings were separated using a wire rack and immersed in fuel in a glass jar as opposed to a glass test tube. An analytical balance (Mettler Toledo model ML 104/03) with a density kit (Mettler Toledo model ML-DNY-43) was used for determining the volume (Figure 1). The O-ring test specimen was weighed in air and then weighed in an auxiliary liquid (de-ionized water was used in this study). The following formula, provided by Mettler Toledo, was used to calculate volume. This calculation accounts for the density of air and the density of water at the ambient testing temperature.

$$V = \alpha \frac{A - B}{\rho_0 - \rho_L}$$

A	=	Weight of the sample in air
B	=	Weight of the sample in the auxiliary liquid
V	=	Volume of the sample
ρ_0	=	Density of the auxiliary liquid
ρ_L	=	Density of air (0.0012 g/cm^3)
α	=	Weight correction factor (0.99985), to take the atmospheric buoyancy of the adjustment weight into account

Figure 1. Analytical Balance and Density Kit Used for Determining Volume

2.3.2.2 Change in Hardness

Change in hardness occurs when aromatic compounds are absorbed and the material softens, or when the fuel extracts plasticizers and the material hardens. The change in hardness was determined per D471 [3], which calls out D2240 [5]. A Type M, micro hardness durometer was used during this study (Shore model 714, Figure 2). Shore M is used for O-rings with a cross-sectional diameter of at least 1.25 mm (0.05 in). The durometer uses a hardened indenter, an accurately calibrated spring, a depth indicator and a flat pressure foot. An O-ring is centered below the pressure foot so that it is held firmly against the O-ring. The spring pushes the indenter into the O-ring and the indicator measures the depth of penetration. The deeper the indentation the softer the material and the lower the indicator reading. Five measurements were taken per sample set.

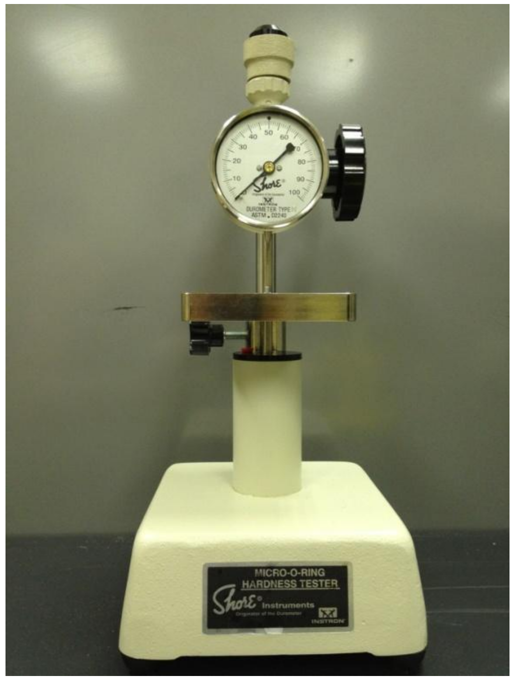

Figure 2. Shore M Durometer

2.3.2.3 <u>Compression Set</u>

Compression set measures a material’s ability to maintain elastic properties after prolonged compressive stress. Compression set was determined per D1414 [6], which calls out D395 [7]. A compression set fixture from Wyoming Test Fixtures was used (Figure 3). Compression set was determined by measuring the cross-sectional thickness of three O-rings. The O-rings were placed in-between metal plates of the compression set fixture along with shim stock. The shim stock thickness was determined to be 75% of the O-rings thickness, so that the O-rings were compressed 25%. Bolts on the compression set fixture were tightened to prevent deflection upon heating. The compression set fixture was then placed in the testing fluid at 40 °C for 70 hours. The cross sectional thickness was measured at the end of the immersion period, and the percent compression set was calculated.

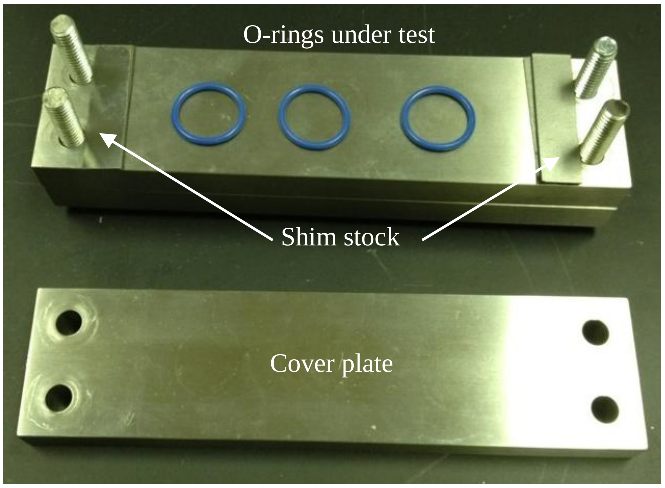

Figure 3. Compression Set Fixture Displaying the O-rings and Shim Stock Used During Testing

2.3.2.4 Tension Testing

Tensile strength is the maximum tensile stress reached in stretching a test piece. Tensile strength was determined per D1414 [6]. A Sintech tensile tester with an O-ring fixture was used for testing (Figure 4). Baseline O-rings that were not immersed in fuel were tested as a reference for the immersed results.

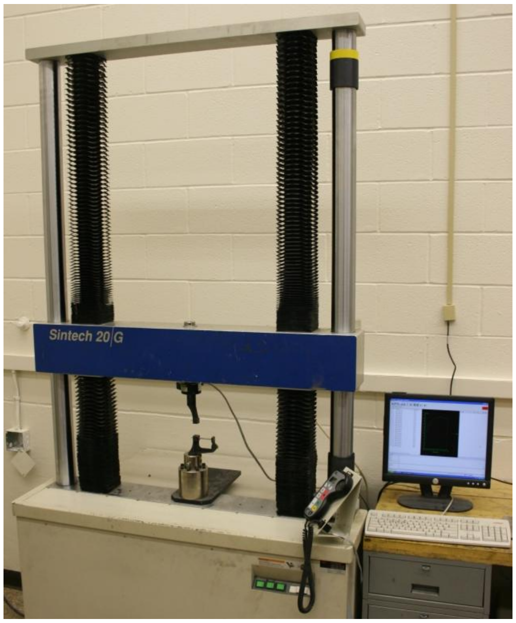

Figure 4. Tensile Tester with O-ring Fixture

2.3.2.5 Cross Sectional Thickness

Similar to the change in volume, the change in thickness relates to whether or not a good seal will form. The thickness was determined per D1414 [8]. An electronic micrometer was used for measurements (CDI model LG2110, Figure 5). An O-ring was centered below the pressure foot of the micrometer, and the digital reading was recorded as the thickness. Five measurements were taken per sample set.

Figure 5. Micrometer Used for Measuring Cross Sectional Thickness

2.4 FUEL SELECTION

Over the last several years, SwRI has performed fit-for-purpose testing on a wide variety of synthetic aviation fuels for the Air Force. Many of these fuels are still available or can be easily obtained. A selection of petroleum-based fuels, synthetic fuels, and blends thereof were assembled to determine the impact of various fuel chemistries on the materials using the test protocols described above.

A variety of fuels were obtained as listed in Table 4. Jet A, JP-8 and diesel were selected as they are currently used in service. The alternative fuels were selected to represent a variety of synthetic pathways and base stocks. Fuel property data can be found in the Interim Report prepared for the Air Force Research Laboratory [7]. Jet A, JP-8 and diesel were the baseline fuels. The Jet A was Valero and additized to make JP-8 using the additives and treat rates shown in Table 5. The diesel was a commercially available ultra low sulfur diesel (ULSD) from Shell. All of the synthetic alternative fuels were provided by the Air Force Research Laboratory at Wright Patterson AFB. All of the fuel, except the diesel, was clay treated to remove water and any additives that were previously added to obtain a clean baseline. The synthetic fuel blends were prepared as 50/50 blends with Jet A, and were then additized to JP-8. The 50/50 synthetic fuel blends will be referred to by the synthetic fuel in the blend. For example, a 50/50 blend of Jet A and Camelina additized to JP-8 will be referred to as Camelina.

Of all the fuel properties, aromatic content is generally assumed to have a significant impact on the properties of elastomers. The effects range from swelling or shrinkage to embrittlement by extraction of key components from the material. The aromatic content of the neat alternative fuels used in this study was essentially zero. The aromatic content of the Jet A used for blending was nominally 18-20 vol%. Therefore, the resulting 50/50 blends had aromatic contents of approximately 8-10 vol%.

Table 4. Test Fuels

Fuel
Sasol FT IPK
R-8 HEFA SPK
Camelina HEFA SPK
Tallow HEFA SPK
Rentech FT SPK
ULSD
Jet A
JP-8

Table 5. Additives and Treat Rates to Blend JP-8

Additive	Units	Treat Rate
Static Dissipater Additive (Stadis 450)	mg/L	1
Corrosion Inhibitor/Lubricity Improver (DCI-4A)	mg/L	15
Fuel System Icing Inhibitor (DIEGME)	Vol%	0.15

2.5 TEST MATRIX

Based on the cumulative information collected above for materials, testing protocols, and fuels, a test matrix was generated. Static soak tests were selected to compare how the various fuels affect a given material. Fuel switch soak tests were selected to evaluate how a given material responds to being switched back and forth between a baseline fuel (diesel and JP-8) and an alternative fuel. This was to simulate if a fuel system were to switch between fuels out in the field.

Static soak tests, fuel switch soak tests and compression set tests were performed. For the static soak testing each of the materials were stored in each of the fuels at 40 °C and 60 °C. Baseline measurements were taken, and then three O-rings were placed in a jar of fuel. Hardness, volume change and cross sectional thickness were measured initially and on a weekly basis for four weeks. At the end of the four week immersion period, final measurements were made along with tensile strength.

Fuel switch testing was performed on each of the materials at 40 °C. Hardness, volume change and cross sectional thickness measurements were made prior to immersion and weekly during storage. Tensile strength was measured at the end of the immersion period. The O-rings were immersed in Fuel A (Table 6) for two weeks and then switched to Fuel B (Table 6) for two weeks. There were two cycles total. In each case, Fuel B is the 50/50 blend as described in section 2.4.

Table 6. Fuel Switch Pairs for Fuel Switch Testing

Fuel A	Fuel B*
Diesel	Sasol IPK
Diesel	R-8
Diesel	Rentech SPK
Diesel	Camelina
Diesel	Tallow
JP-8	Sasol IPK
JP-8	R-8
JP-8	Rentech SPK
JP-8	Camelina
JP-8	Tallow
*50/50 blends with Jet A and the fuel listed, then additized with JP-8 additives	

Compression set testing was performed on all the O-rings (except for Teflon® as it is not an elastomer) in each of the fuels. Three O-rings, for each material, were analyzed per test. The samples were tested for 70 hours at 40 °C.

3.0 RESULTS AND DISCUSSIONS

The following sections provide details from the analysis. The data is grouped by O-ring material and property test. For the static soak testing the overall percent change in the property from the initial to final week is given. For the fuel switch testing, the average weekly value was plotted. The tensile strength data are plotted with individual and average results.

3.1 STATIC SOAK TESTS

Polyurethane and fluorosilicone showed the greatest property changes resulting from exposure to the fuel. Teflon® is affected the least followed by Viton® and then nitrile. When comparing the results between the 40 °C and 60 °C data, it appears that the temperature difference did not lead to a significant difference in the results.

There were some small differences among the properties. These are discussed in the subsections below.

3.1.1 Fluorosilicone (Figure 6 to Figure 10)

The material selection research showed that fluorosilicone is used in the field as O-rings. Since a good seal is important for O-rings, that will be highlighted when evaluating the property changes.

The hardness data shows that fluorosilicone became softer in all of the fuels. This suggests that fluorosilicone is absorbing aromatic compounds from the fuels. The alternative fuel data was similar to that of the fuels baseline. Jet A had a smaller percent change than diesel and JP-8. Sasol IPK also had a smaller percent change siliar to Jet A. The 60 °C data for Camelina had the largest percent change of -8.6%.

The thickness data demonstrated that fluorosilicone decreased in size when soaked in all of the fuels except for the HEFA fuels, Camelina and Tallow. In these fuels, fluorosilicone increased about 1%. This change is not significant, but would need to be checked with the tolerance of the equipment to ensure a proper fit in order to prevent leaks.

The volume data is consistent between the alternative blends and the baseline fuels. The data is also consistent for tensile strength and compression set. This indicates that fluorosilicone should behave the same way when exposed to the alternative fuels as it currently does with the baseline fuels.

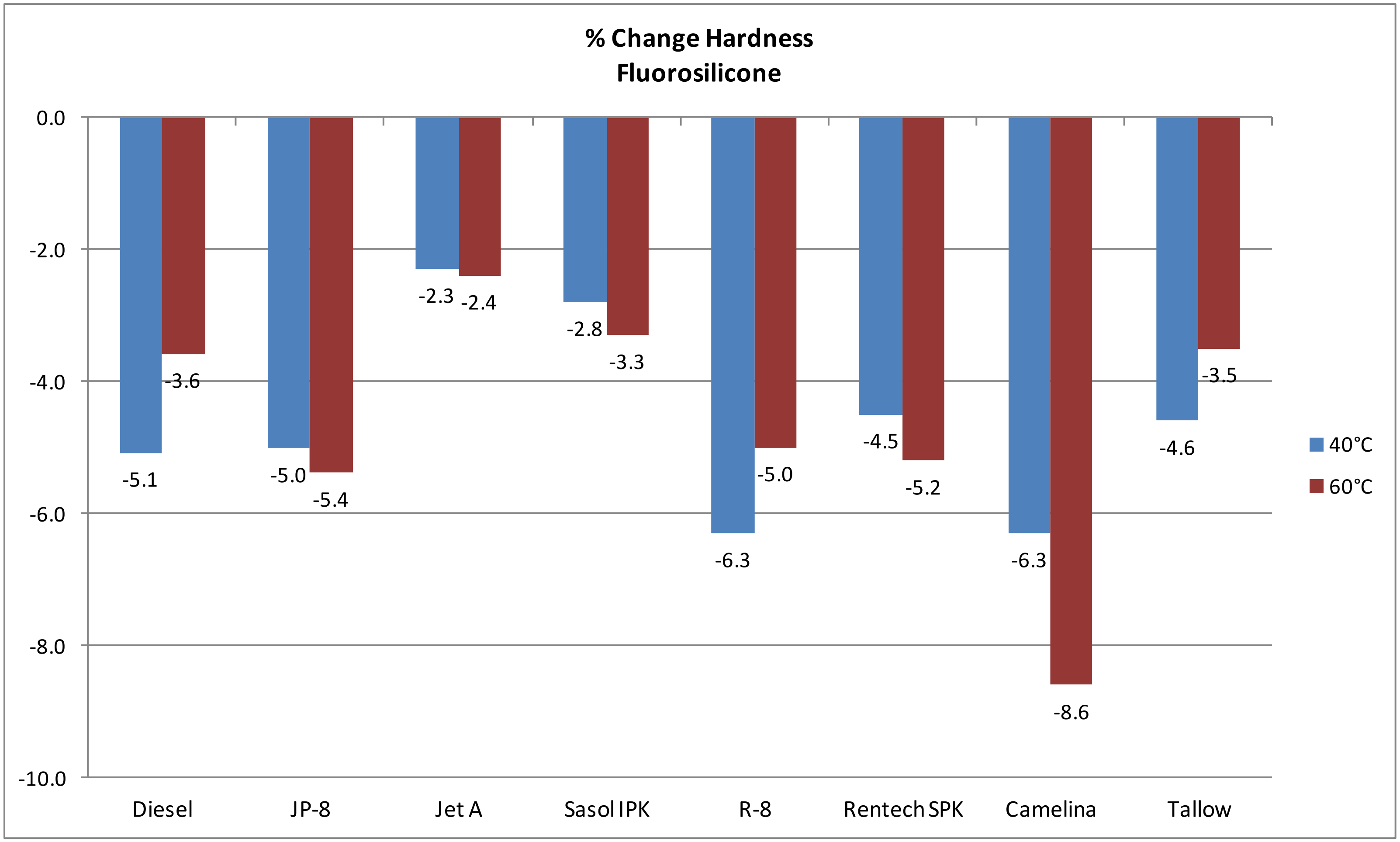

Figure 6. Change in Hardness for Fluorosilicone Samples after Four Weeks

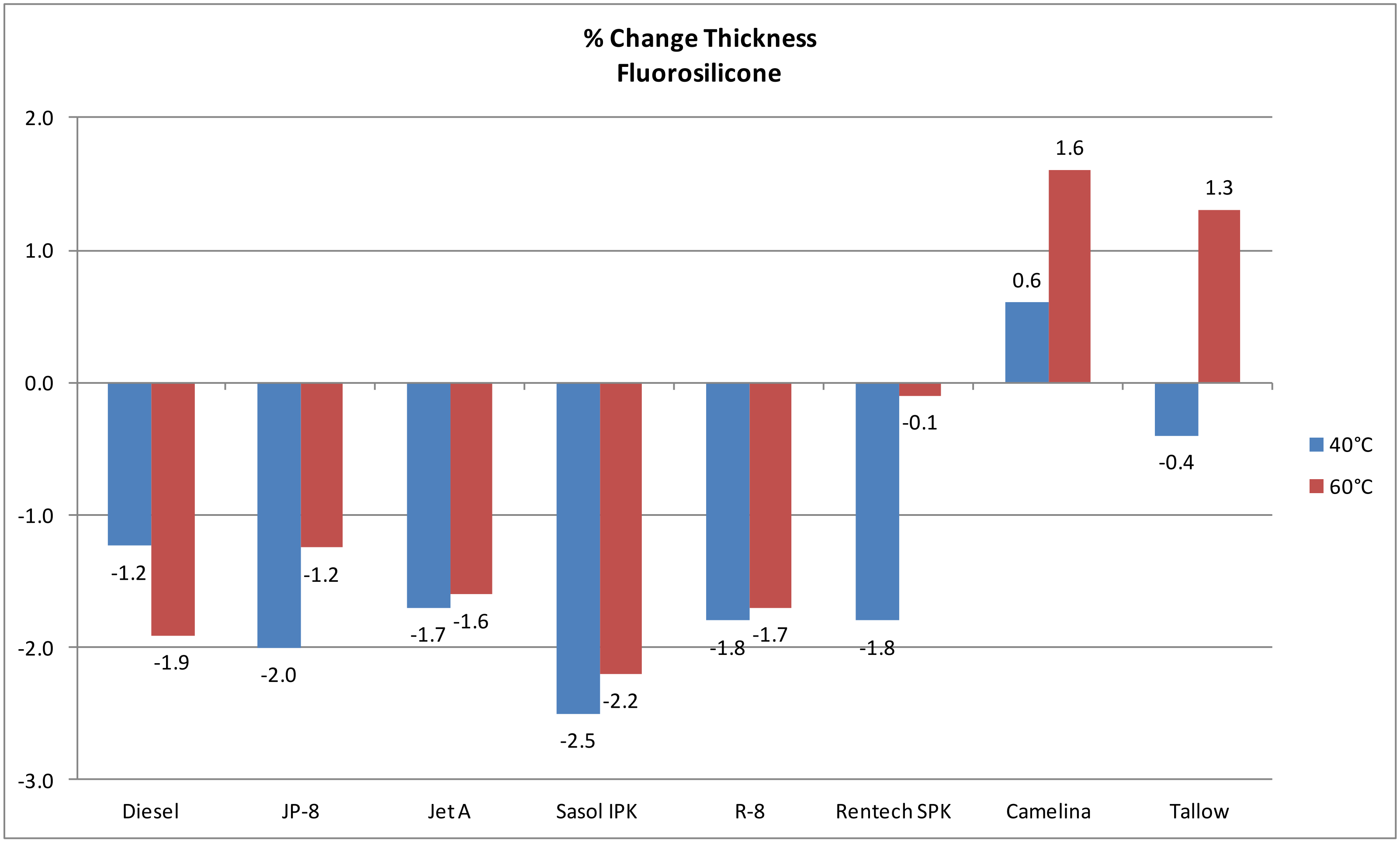

Figure 7. Change in Thickness for Fluorosilicone Samples after Four Weeks

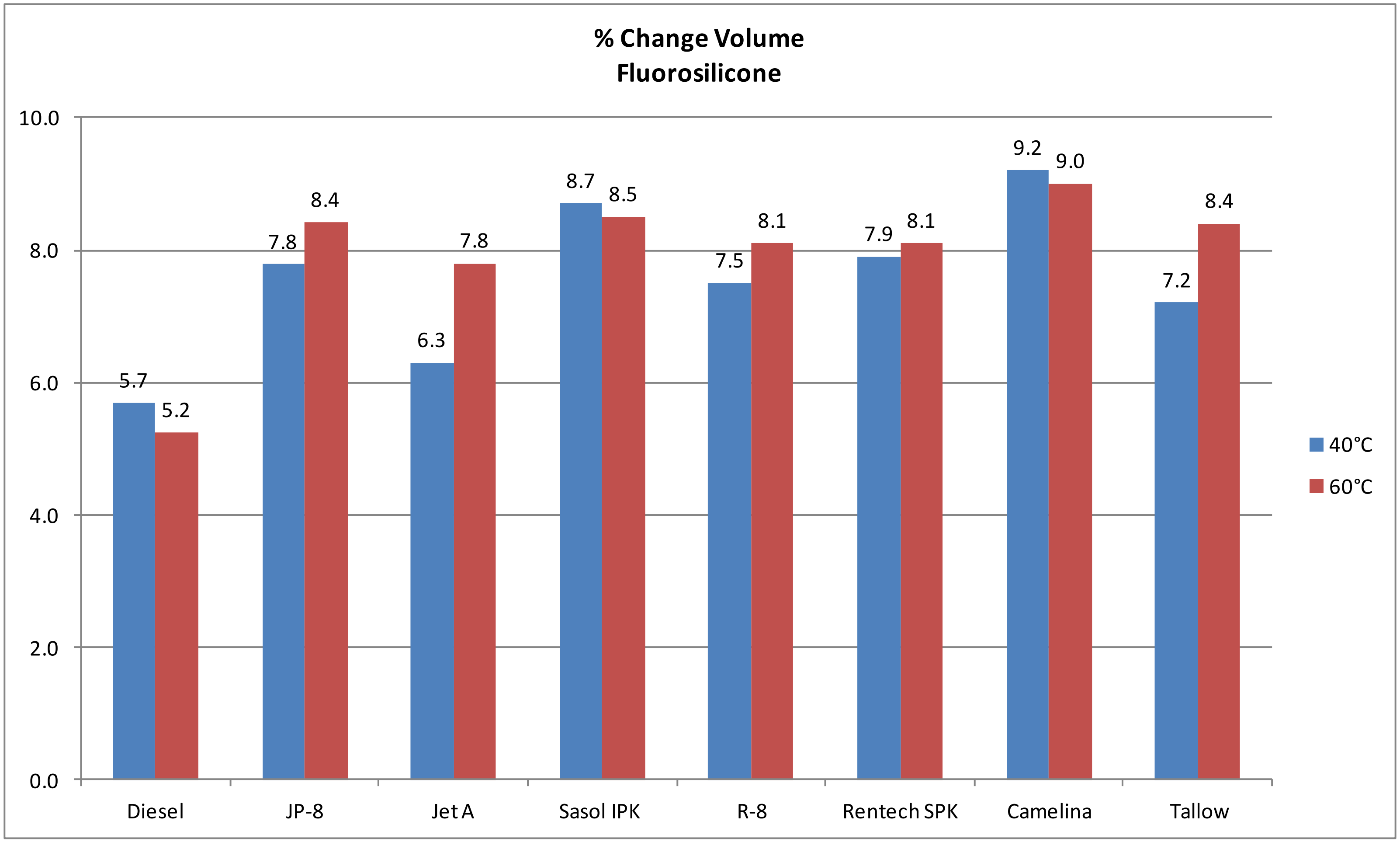

Figure 8. Change in Volume for Fluorosilicone Samples after Four Weeks

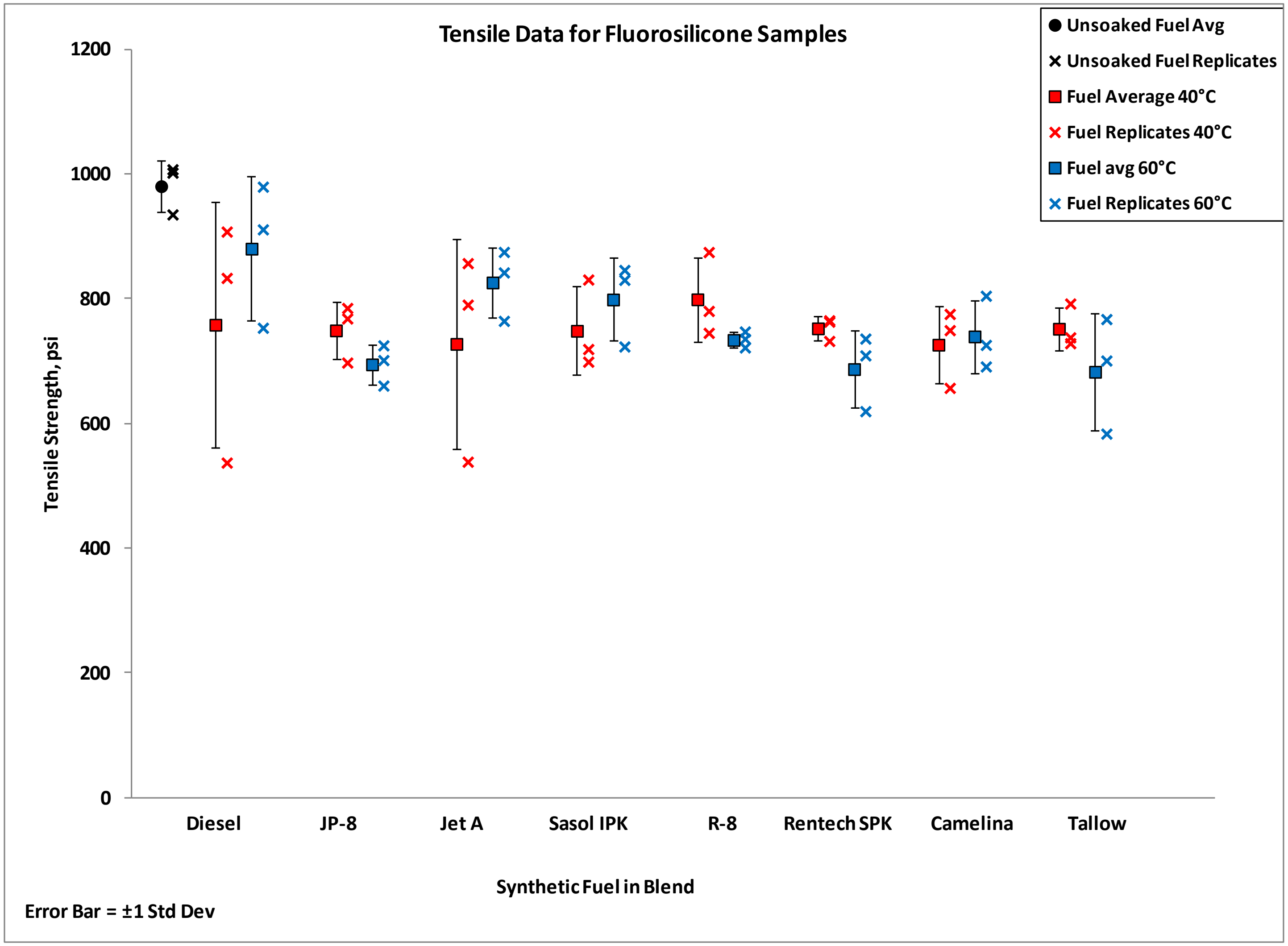

Figure 9. Tensile Strength Data for Fluorosilicone Samples after Four Weeks

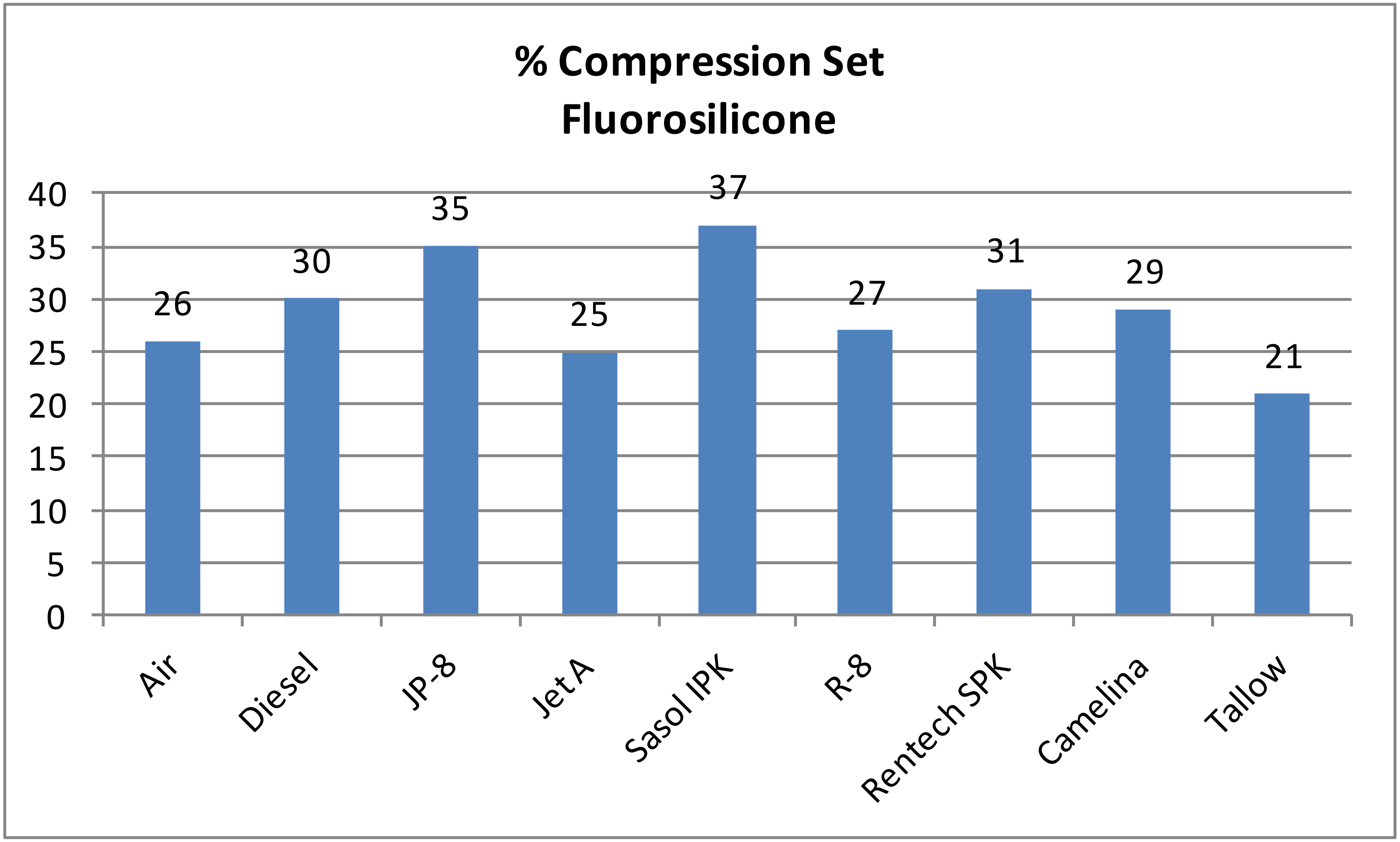

Figure 10. Compression Set Data for Fluorosilicone Samples

3.1.2 Nitrile (Figure 11 to Figure 15)

The material selection research showed that nitrile is used in the field as O-rings and gaskets which need to seal properly. This will be highlighted when evaluating the property changes.

The hardness data showed that nitrile became harder in all of the fuels except Rentech SPK and Camelina. In these fuels it became softer by about 1.5%.

The Nitrile thickness data was consistent and showed that nitrile became thicker upon exposure. It increased the least in R-8.

The Nitrile increased in volume and the alternative fuel blends were consistent with the baseline fuel. The 60 °C values for Rentech SPK and R-8 increased the least, but not significantly.

The data was also consistent for tensile strength and compression set. The compression set for diesel was the highest at 11%. The alternative fuel blends were similar to JP-8 and Jet A, approximately 3-4%, except for Tallow which was at 9%.

With the small differences observed between the alternative fuel property data and the baseline property data, nitrile O-rings and gaskets should still seal properly when exposed to the alternative fuels.

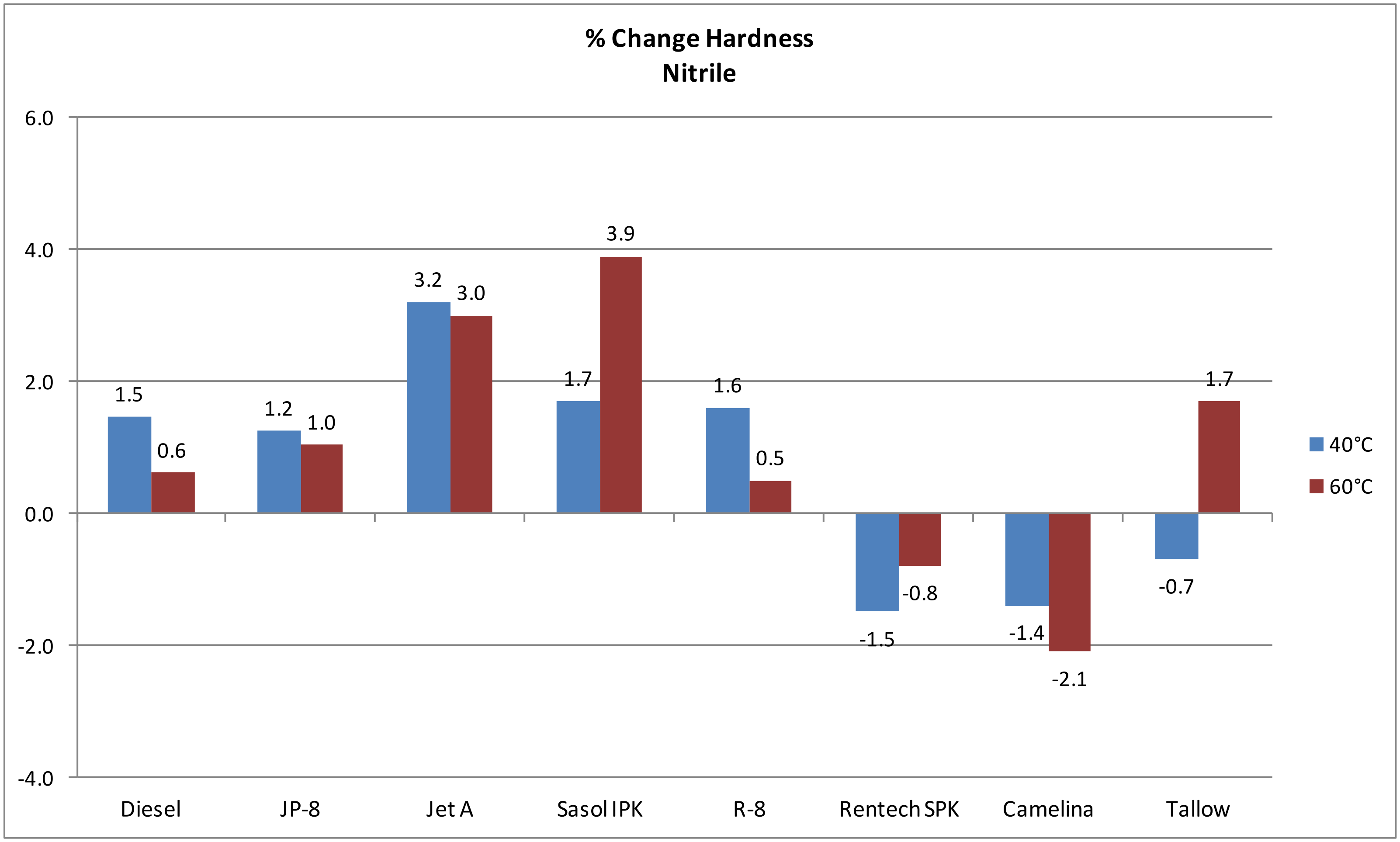

Figure 11. Change in Hardness for Nitrile Samples after Four Weeks

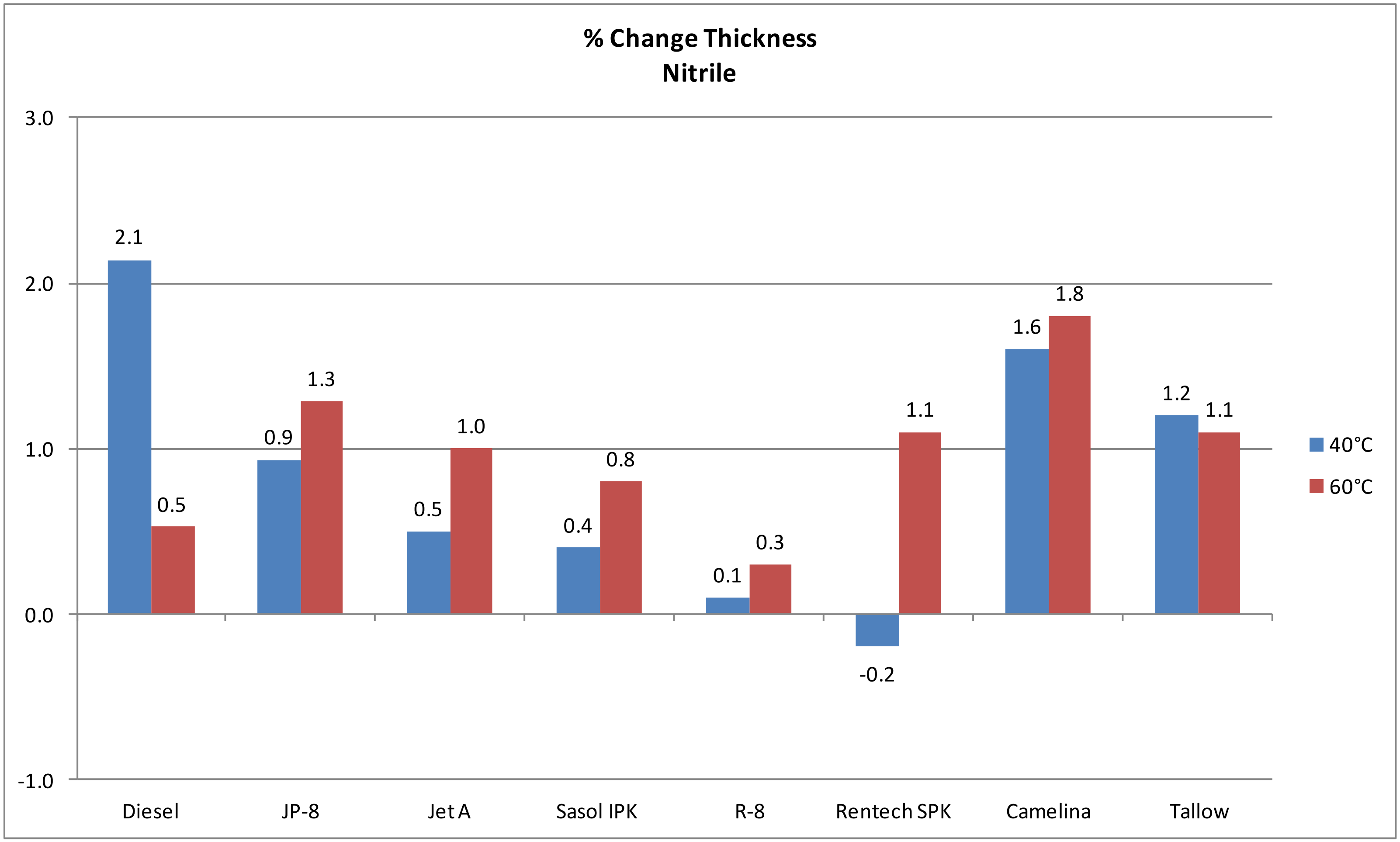

Figure 12. Change in thickness for Nitrile Samples after Four Weeks

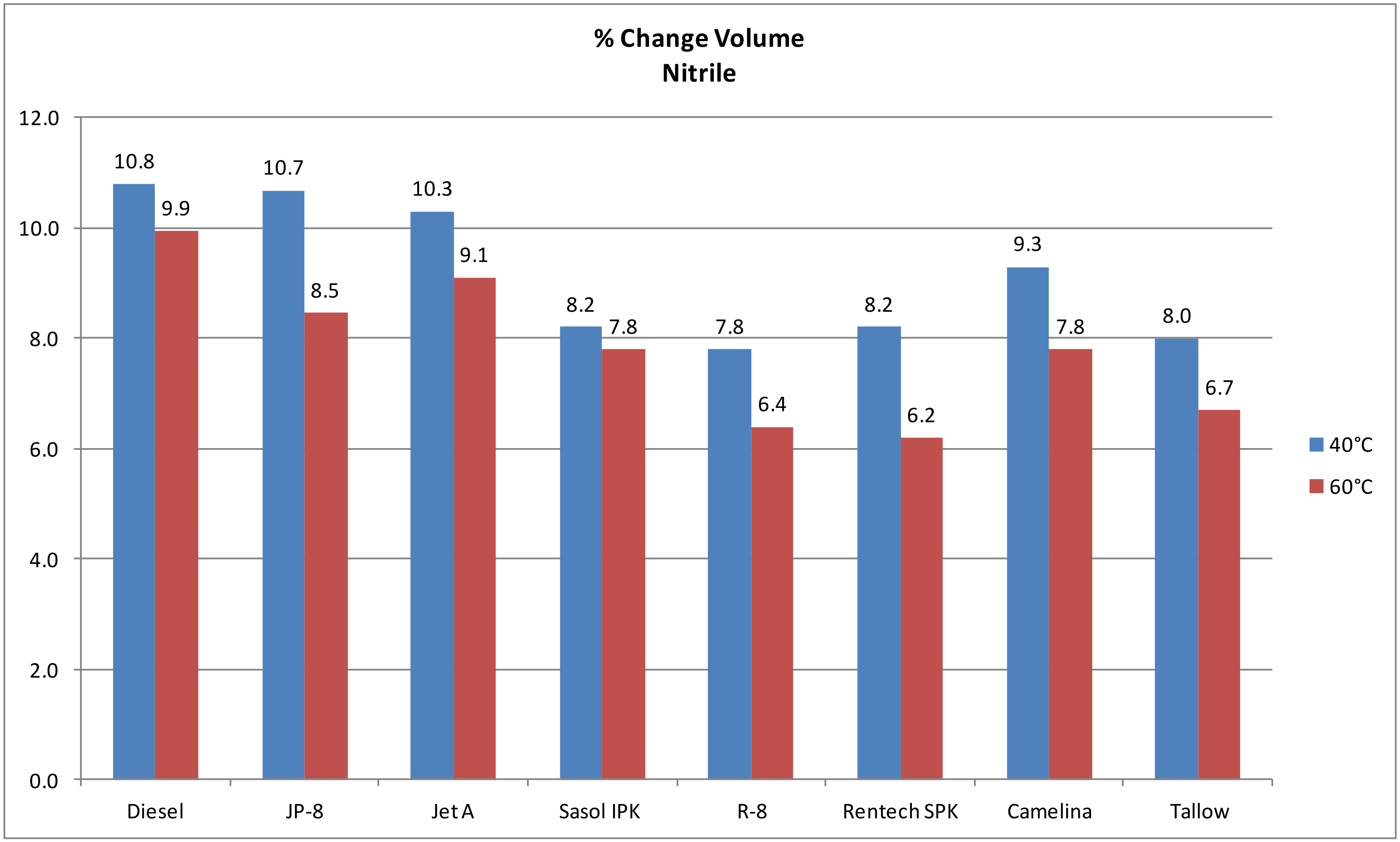

Figure 13. Change in Volume for Nitrile Samples after Four Weeks

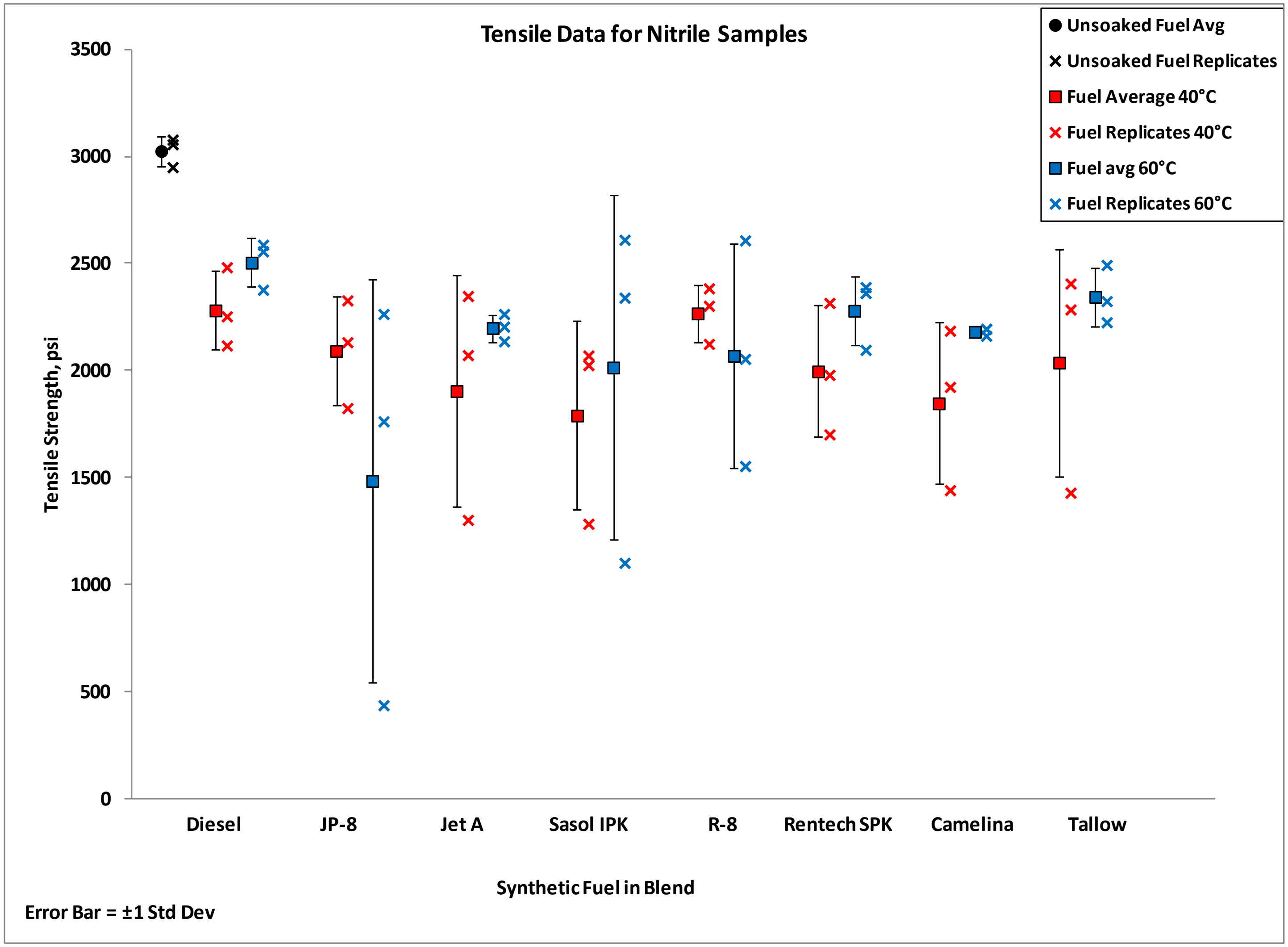

Figure 14. Tensile Strength Data for Nitrile Samples after Four Weeks

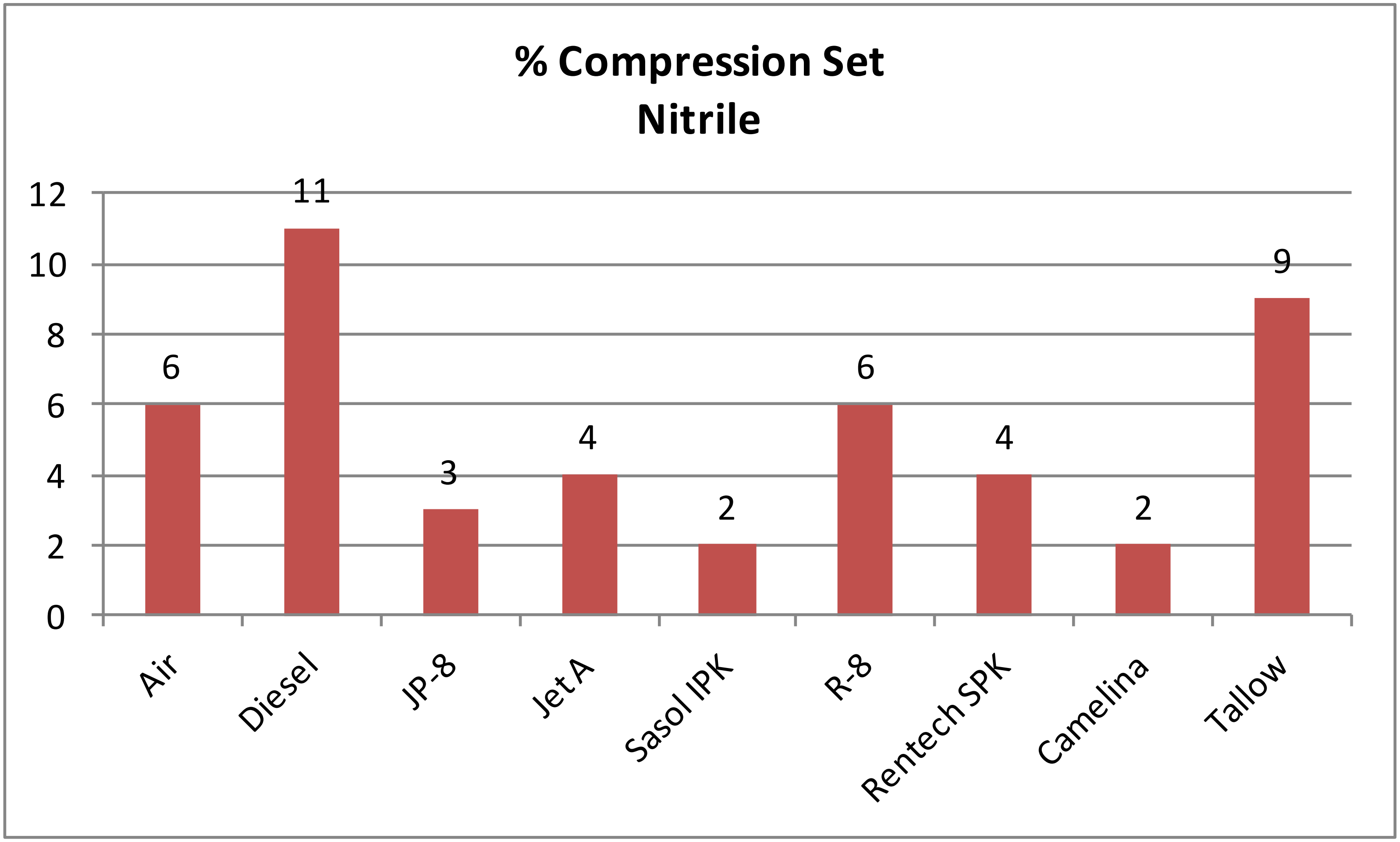

Figure 15. Compression Set Data for Nitrile Samples

3.1.3 Polyurethane (Figure 16 to Figure 20)

The material selection research showed that polyurethane is used in the field as O-rings and gaskets. Since a good seal is important, that will be highlighted when evaluating the property changes.

The hardness data indicated that polyurethane became softer in all of the fuels. R-8 and Rentech SPK had the greatest affect. Sasol IPK's hardness change was the most similar to the baseline fuels at -5.8%.

Polyurethane increased in thickness and volume, but the percent change was less in the alternative fuel blends than the baseline fuels. Polyurethane increased the least in thickness in R-8. It would need to be evaluated if the polyurethane O-rings would swell enough in the equipment in field. If they do not swell enough in the alternative fuel blends than leaks would likely occur.

The tensile strength was slightly higher for the alternative fuel blends than the baseline fuels. The data is relatively consistent among the alternative fuel blends.

The alternative fuel blends had similar compression set to the diesel baseline value of 12%, except R-8 which was similar to JP-8 at 6%.

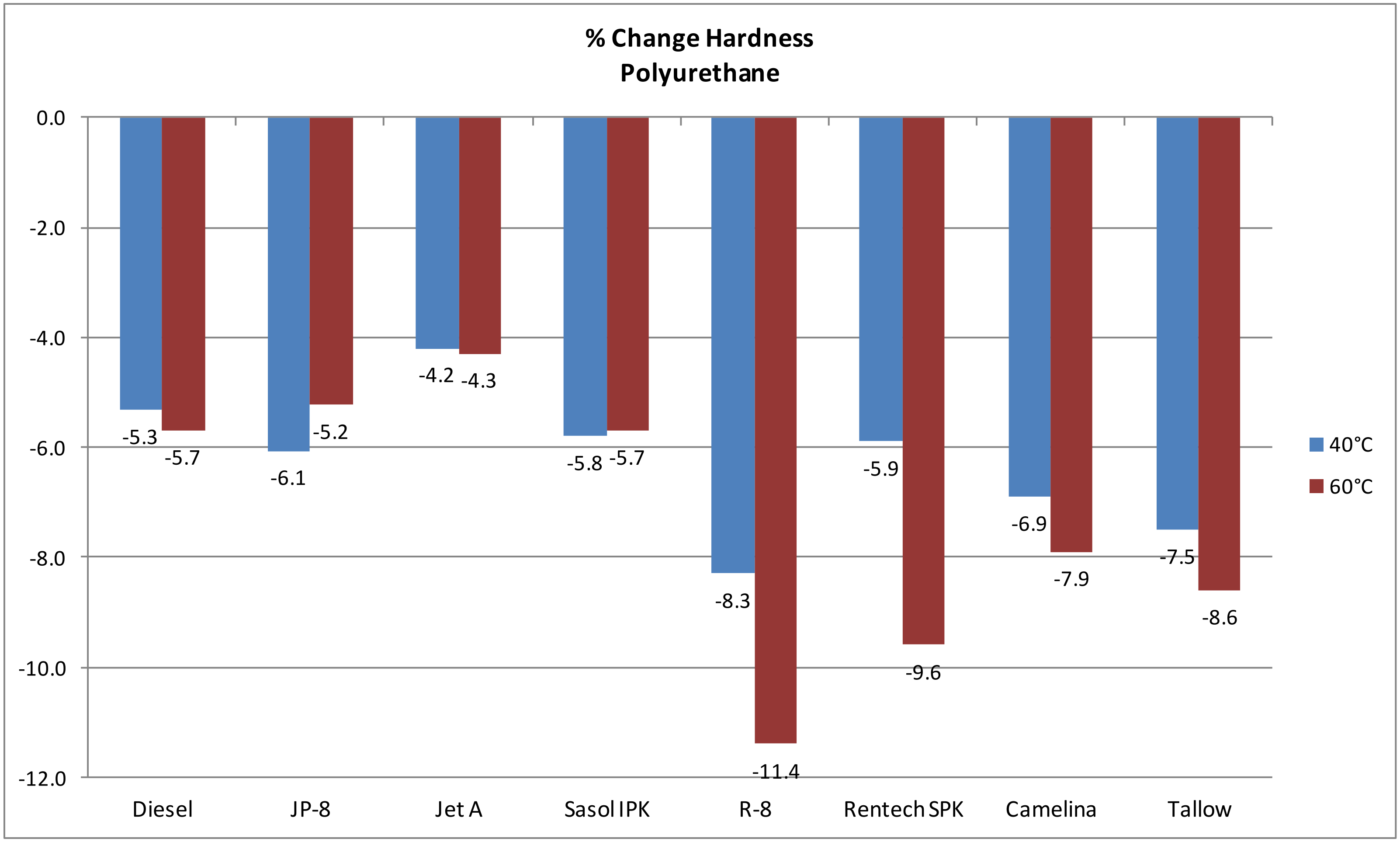

Figure 16. Change in Hardness for Polyurethane Samples after Four Weeks

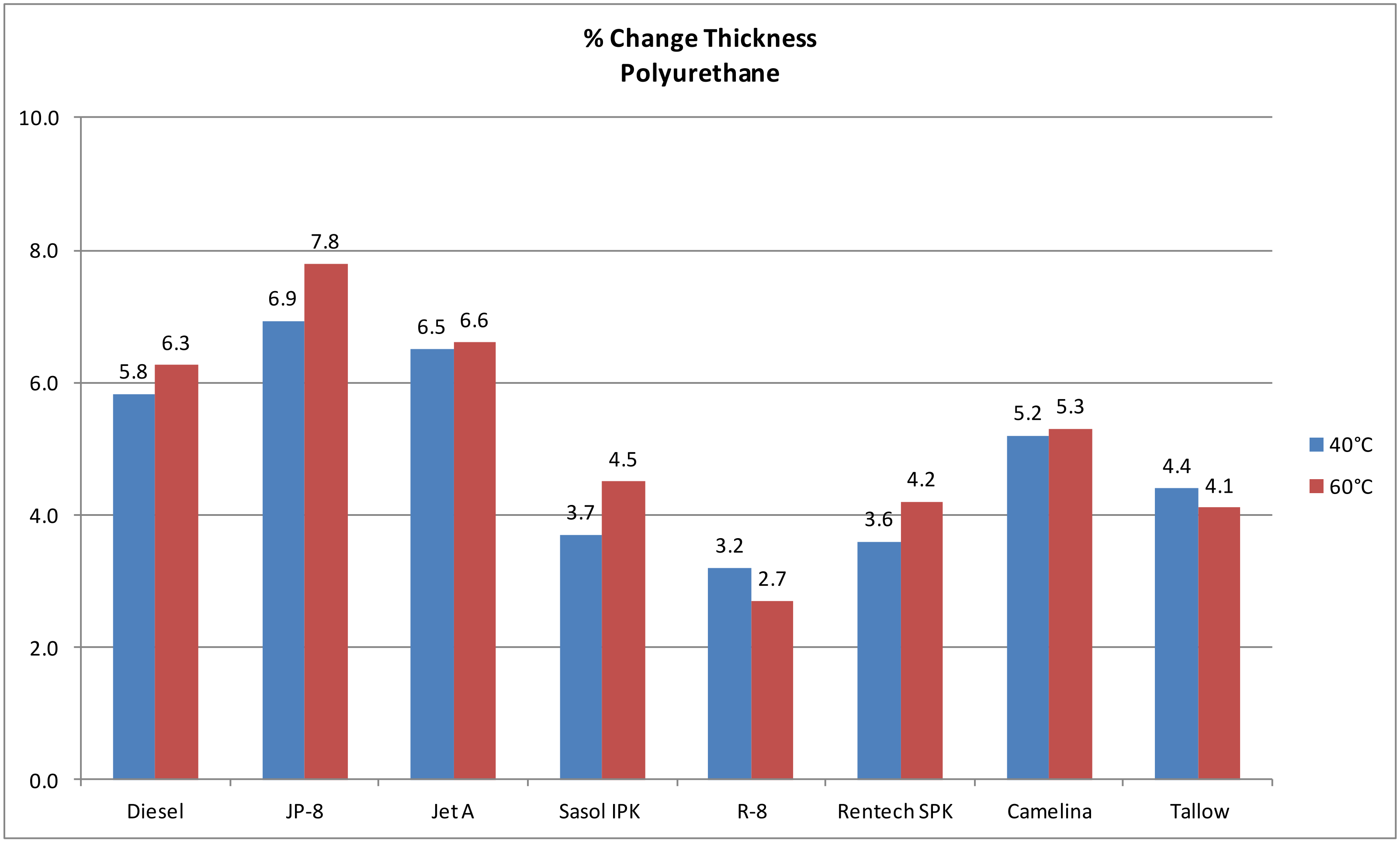

Figure 17. Change in Thickness for Polyurethane Samples after Four Weeks

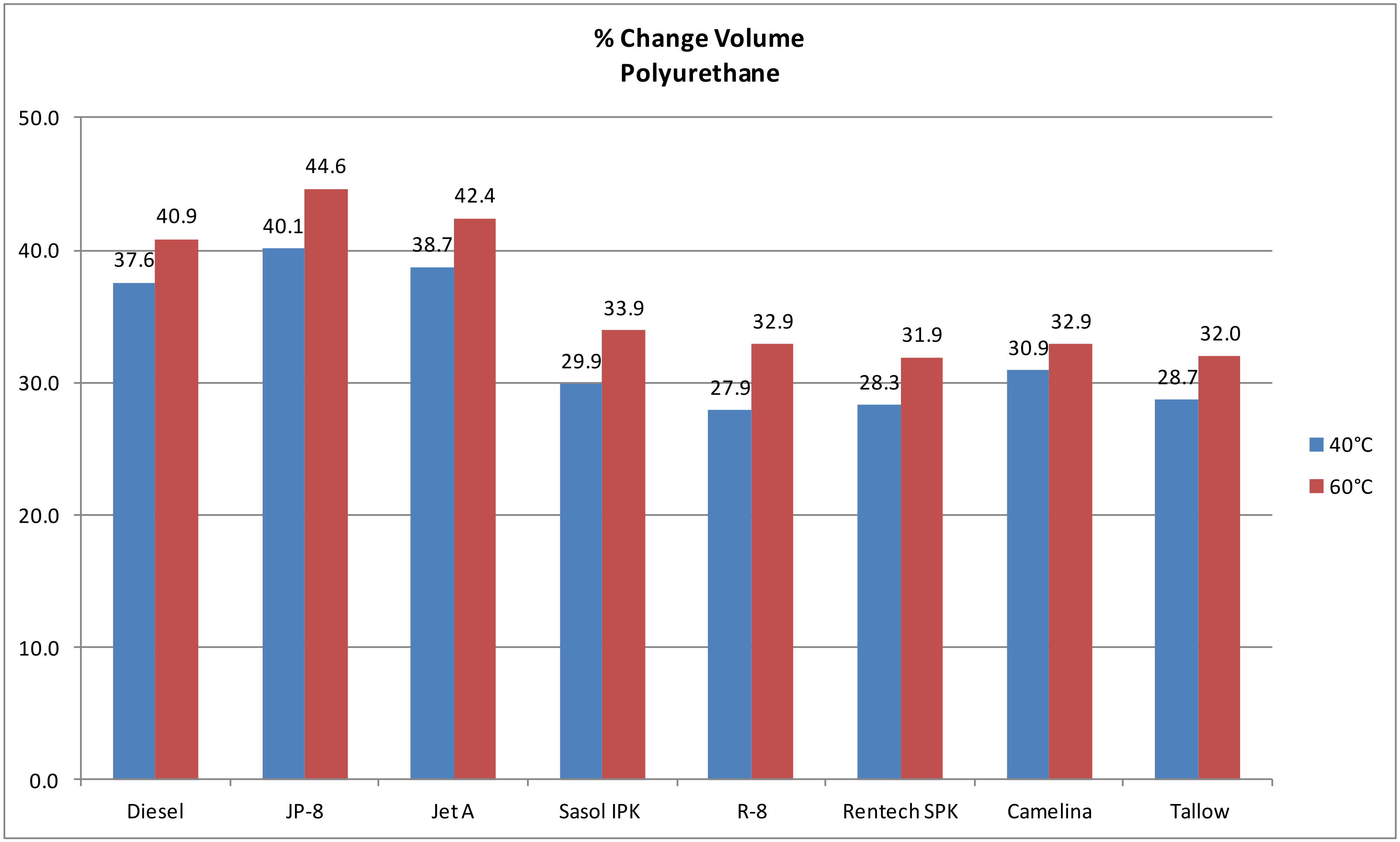

Figure 18. Change in Volume for Polyurethane Samples after Four Weeks

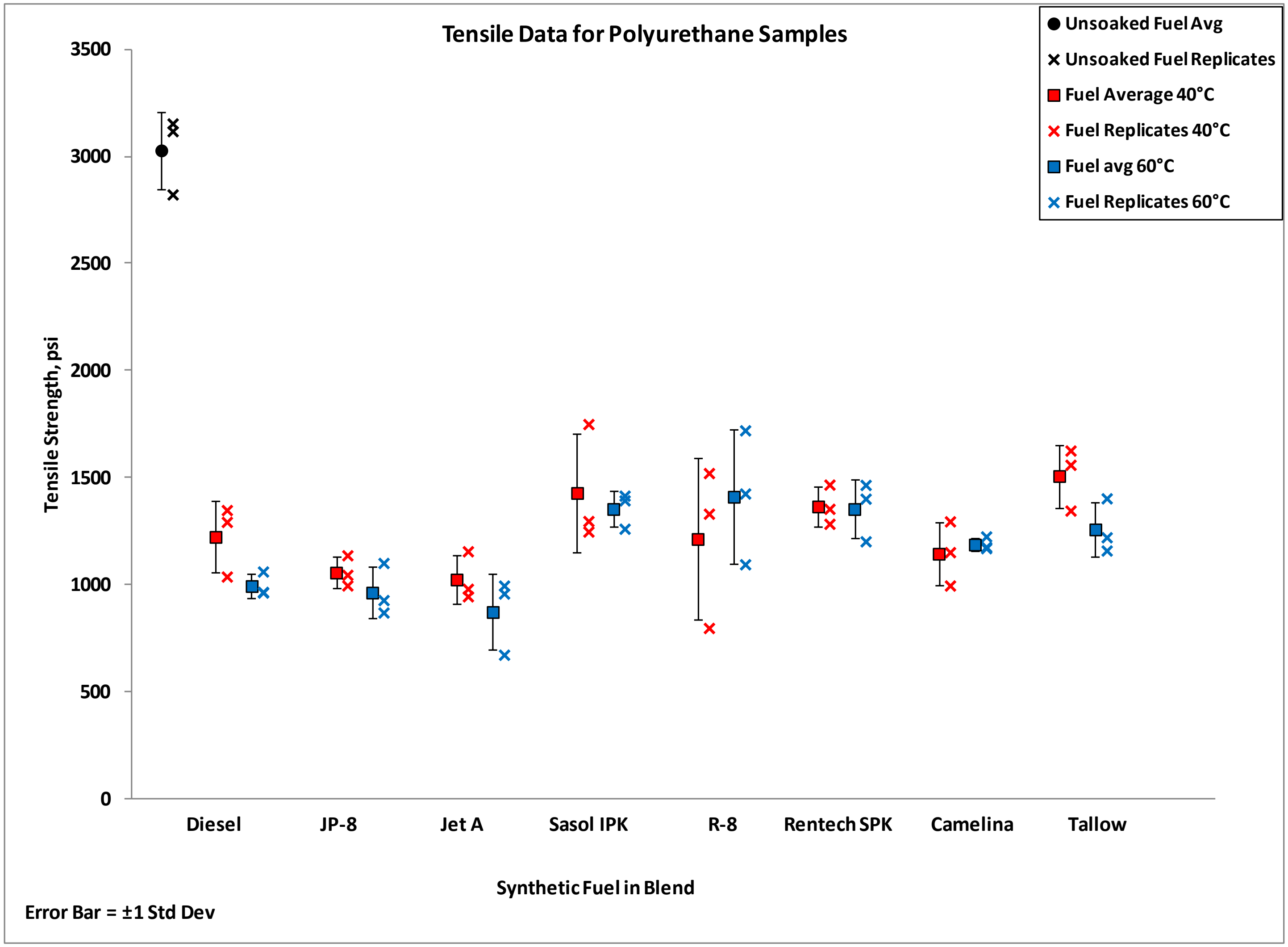

Figure 19. Tensile Strength Data for Polyurethane Samples after Four Weeks

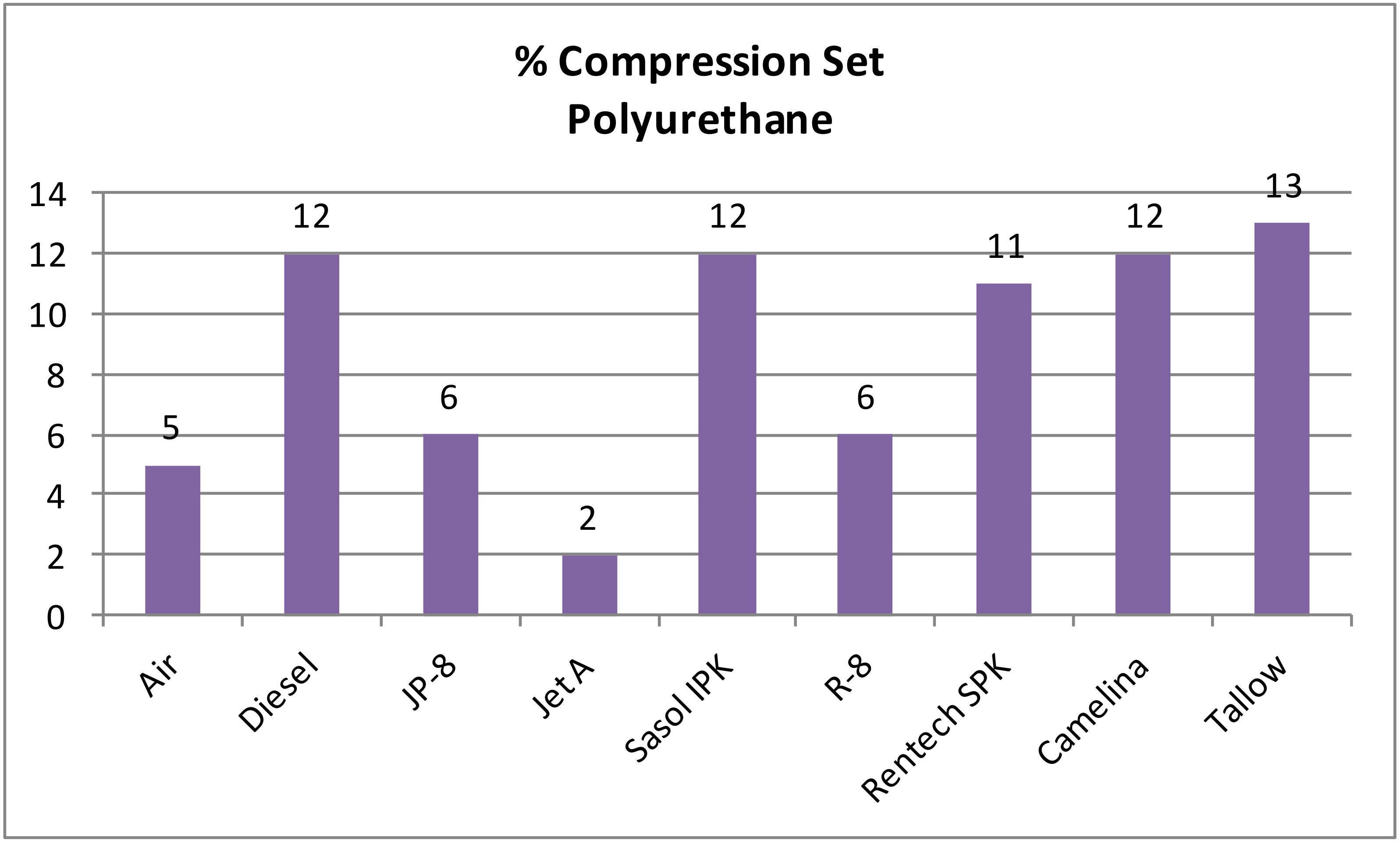

Figure 20. Compression Set Data for Polyurethane Samples

3.1.4 Viton® (Figure 21 to Figure 25)

The material selection research showed that Viton® is used in the field as gaskets. Once again a proper seal will be important.

The hardness data was inconsistent. In some fuels Viton® became softer, and in other fuels harder. It became softer in JP-8, R-8, Rentech SPK, Camelina and 40 °C Tallow. It became harder in diesel, Jet A, Sasol IPK and 60 °C Tallow.

The thickness data was also inconsistent, but the percent changes were small. The largest changes were -0.8% in R-8 and 1.2% in Camelina. Since the thickness is not affected much, it is reasonable to speculate that there should not be a problem in obtaining a proper seal and preventing leaks.

The volume data was more consistent with an increase in volume (~2%). The 40 °C R-8 did decrease by 0.7%, but the 60 °C data did increase by 2.4%. The volume data helps support the thickness data in that a proper seal should still form when Viton® is exposed to the alternative fuel blends.

The tensile strength data was consistent between the alternative fuel blends and the baseline data. The compression set data was also consistent with Rentech SPK and Tallow having the largest compression set at 22% and 24% respectively.

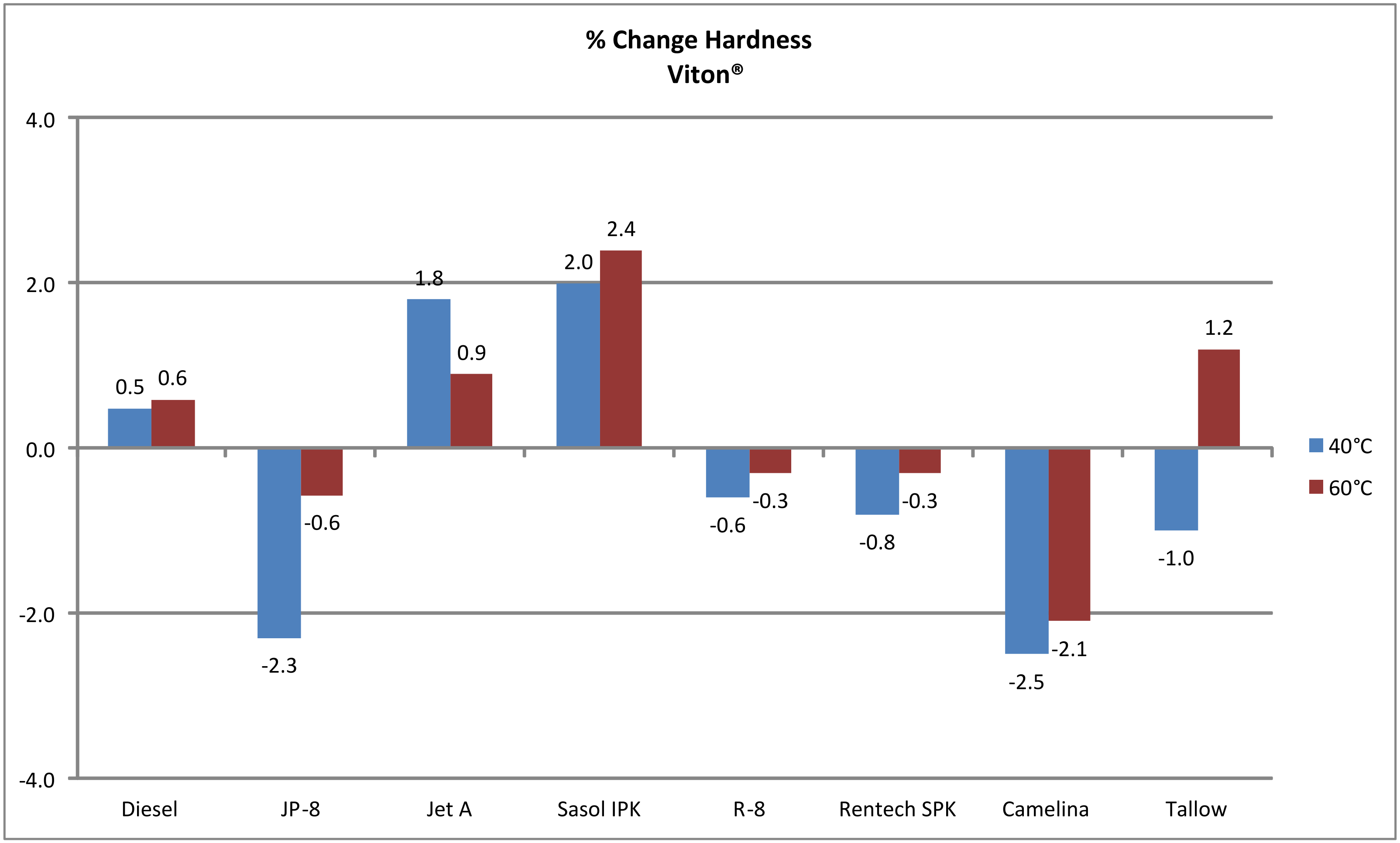

Figure 21. Change in Hardness for Viton® Samples after Four Weeks

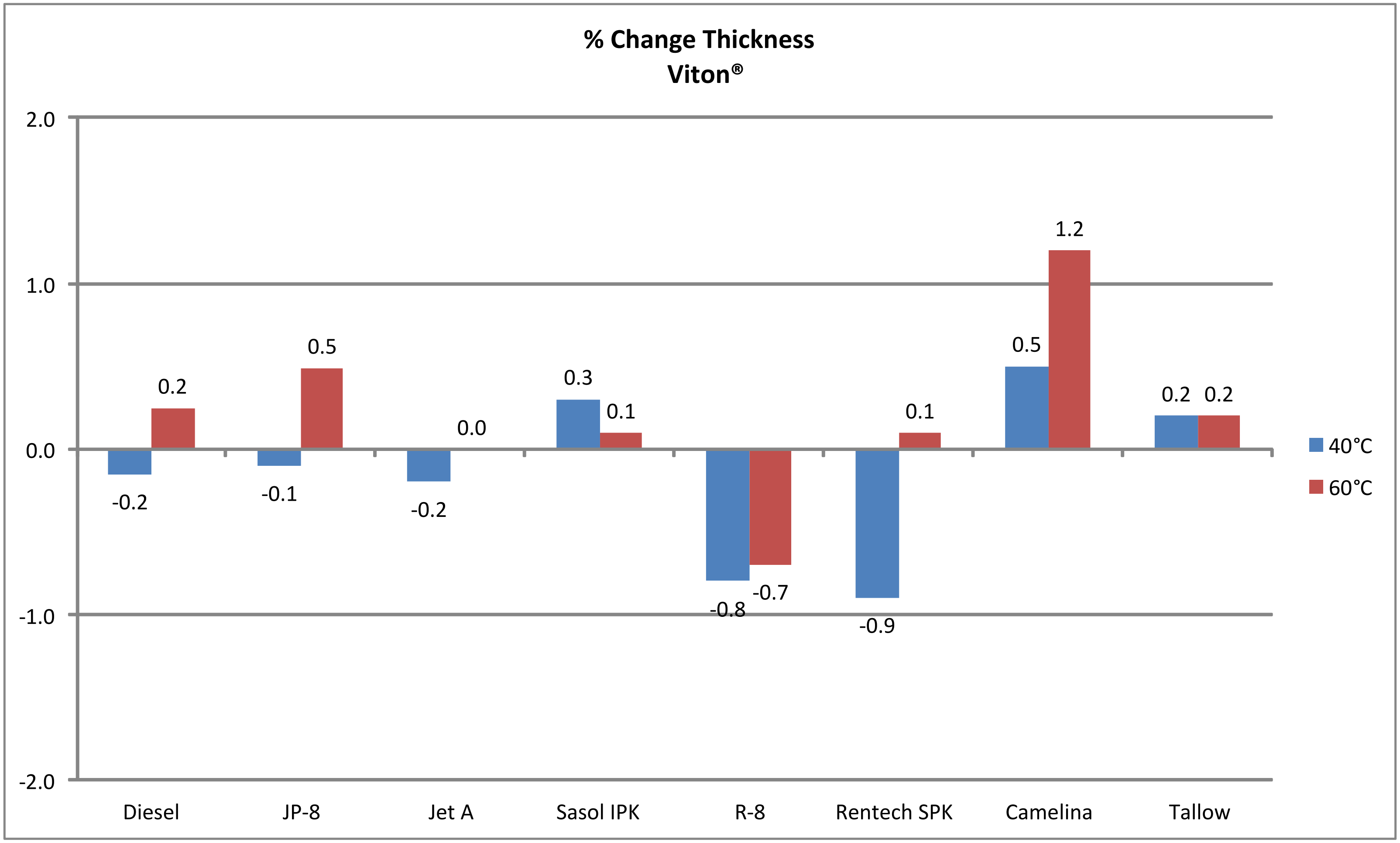

Figure 22. Change in Thickness for Viton® Samples after Four Weeks

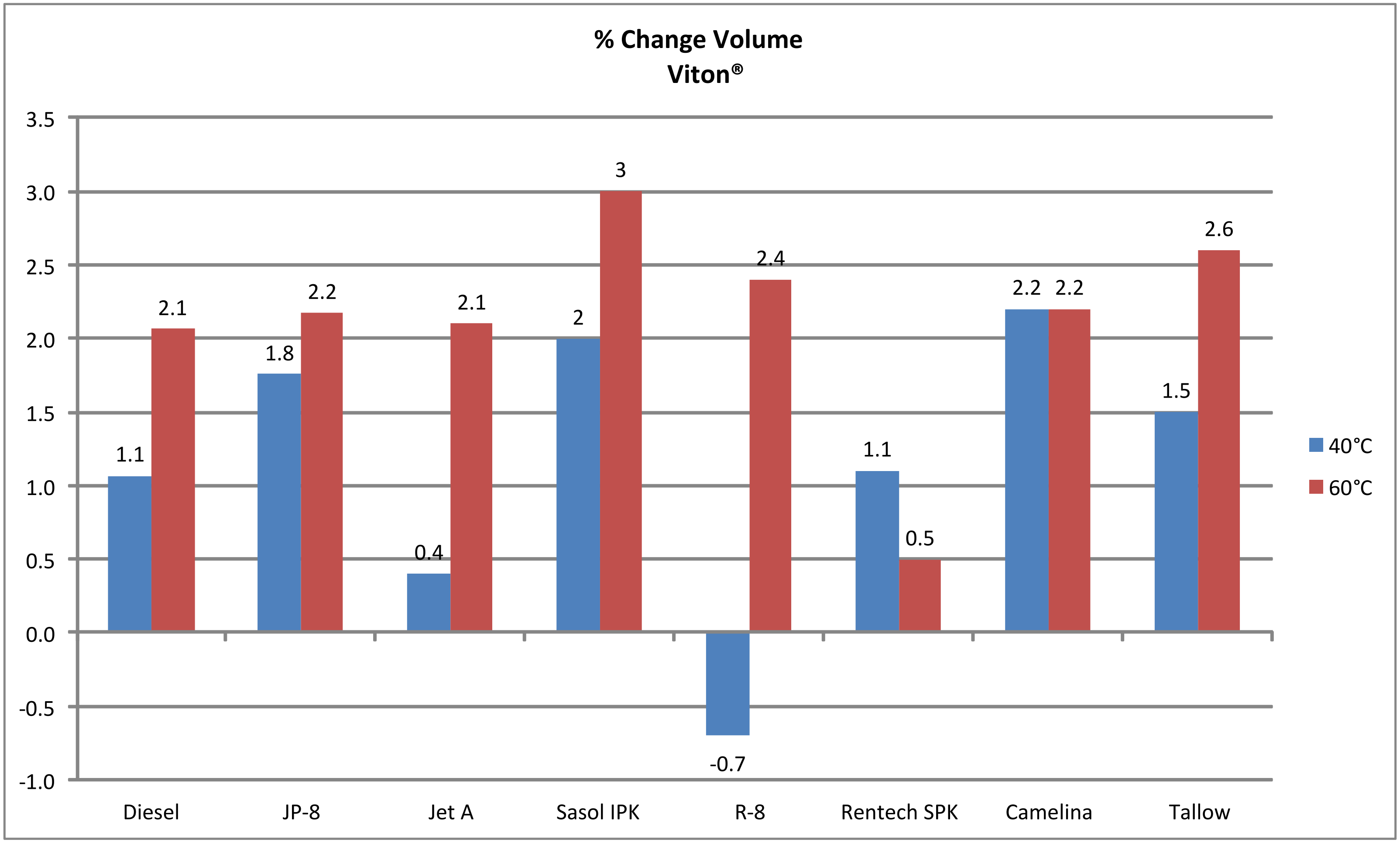

Figure 23. Change in Volume for Viton® Samples after Four Weeks

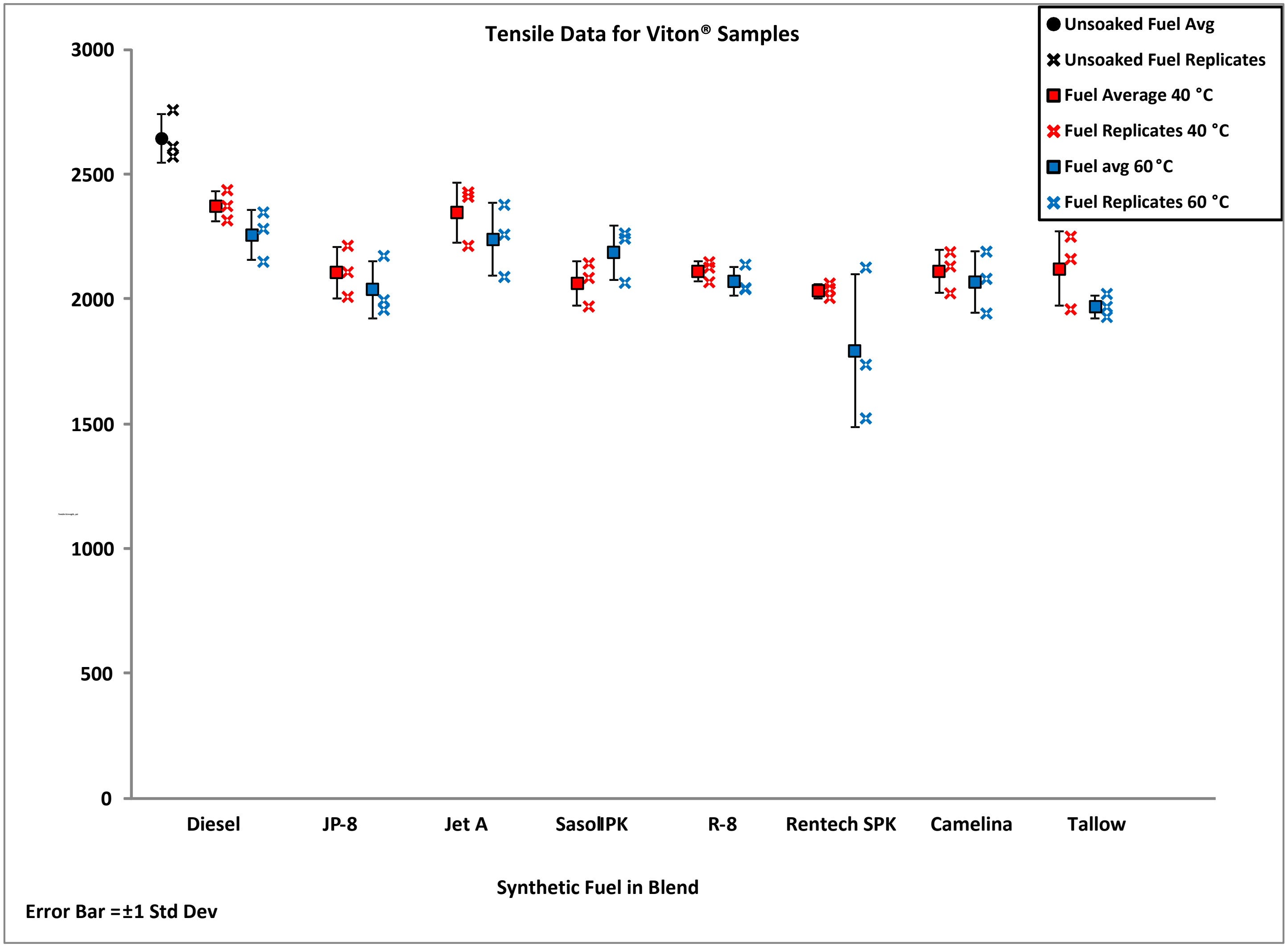

Figure 24. Tensile Strength Data for Viton® Samples after Four Weeks

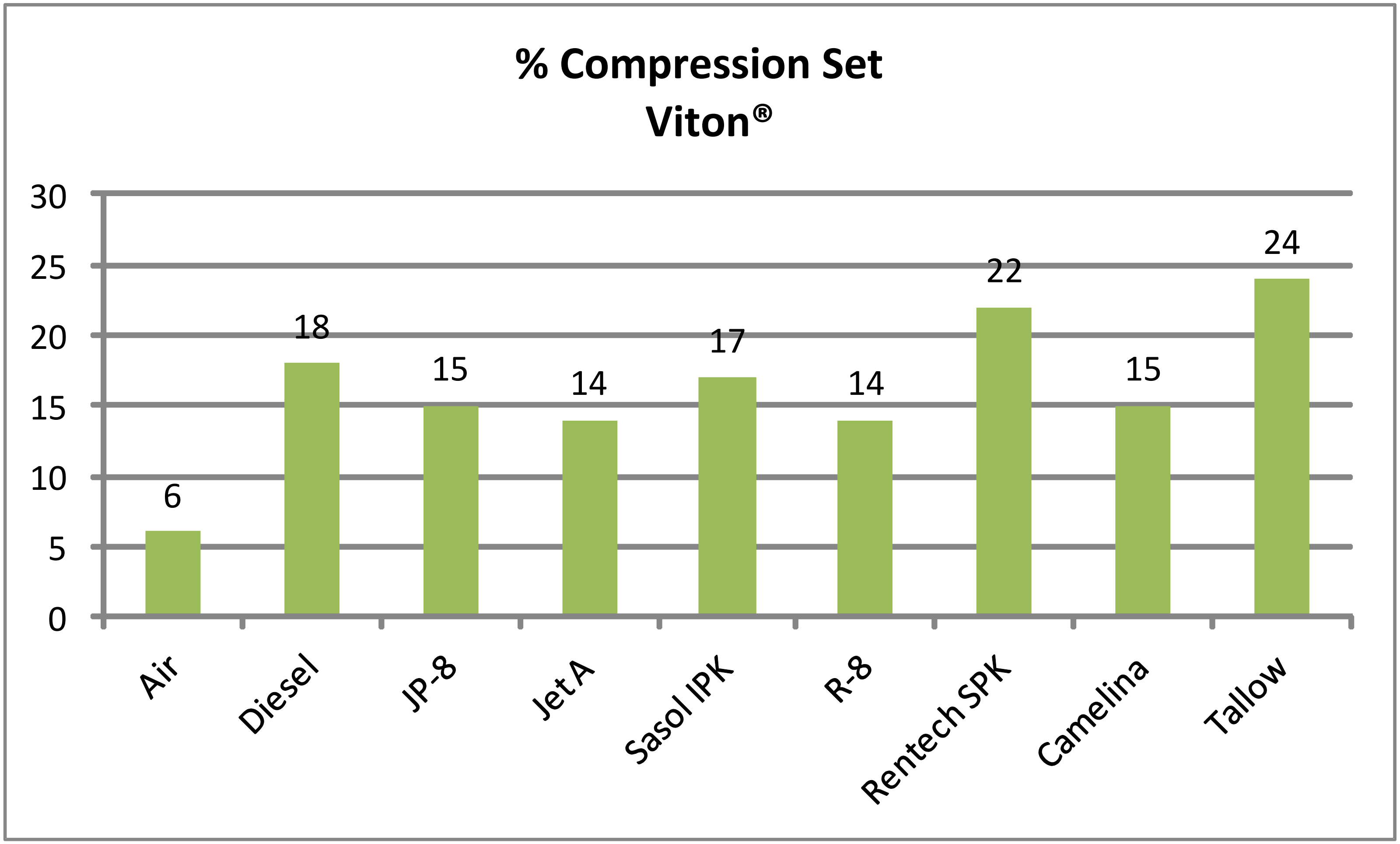

Figure 25. Compression Set Data for Viton® Samples

3.1.5 Teflon® (Figure 26 to Figure 29)

The material selection research showed that Teflon® is used in the field for hoses. A proper seal is not important, but rather a general compatibility.

The hardness data was consistent with an increase in hardness, except for Camelina. Camelina showed a decrease in hardness at both soak temperatures.

The thickness data was inconsistent but the changes observed were small. The thickness decreased with diesel, JP-8 and Sasol IPK. The thickness increased with Jet A, Rentech SPK, Camelina and Tallow. No change was observed with R-8.

On average, the volume swell decreased except for a couple of test points. The volume increased by 0.1% with R-8 at 60 °C and 0.2% with Tallow at 60 °C. Such small fluctuations suggest an insignificant change.

The tensile data were consistent among the alternative fuel blends and baseline data.

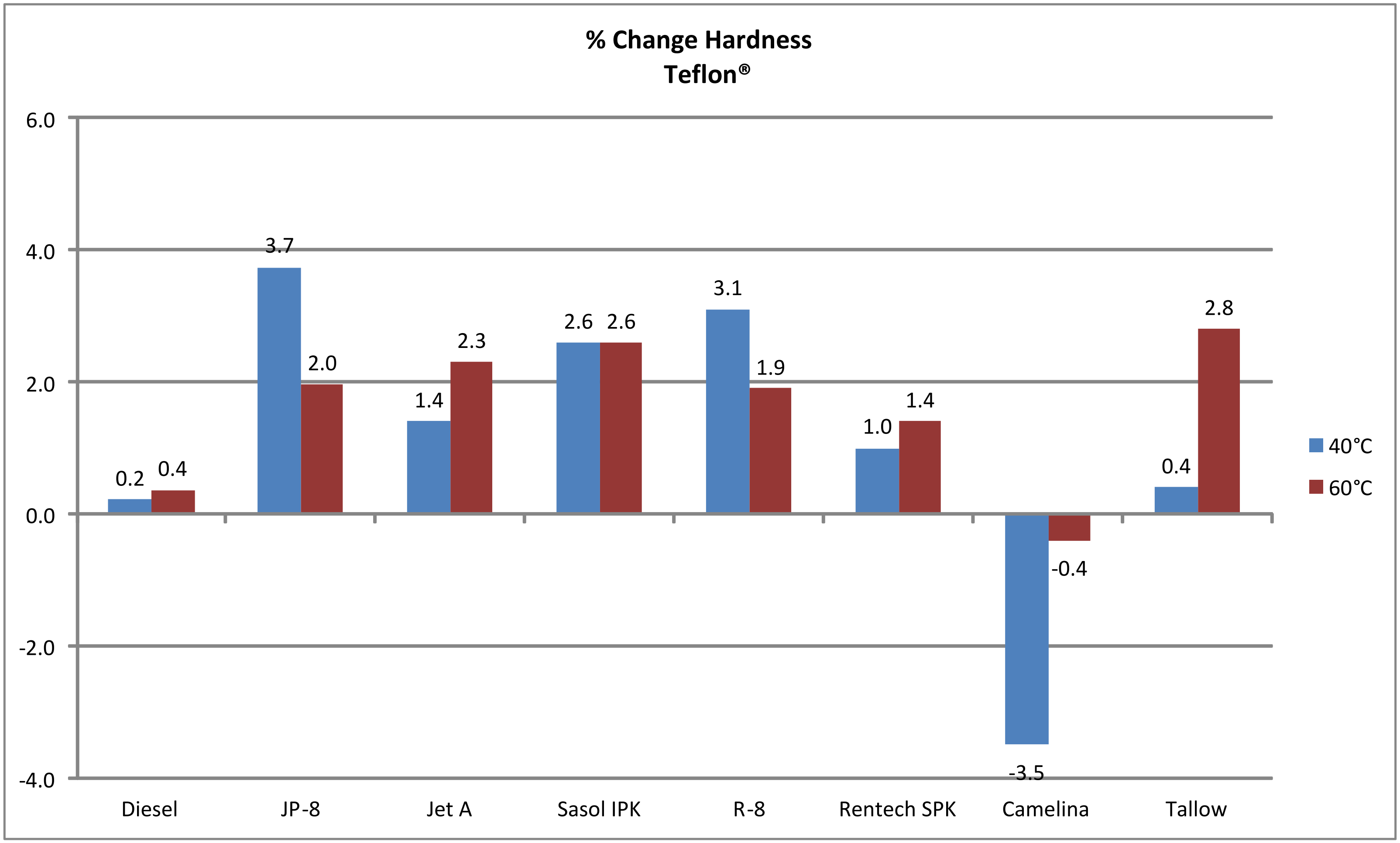

Figure 26. Change in Hardness for Teflon® Samples after Four Weeks

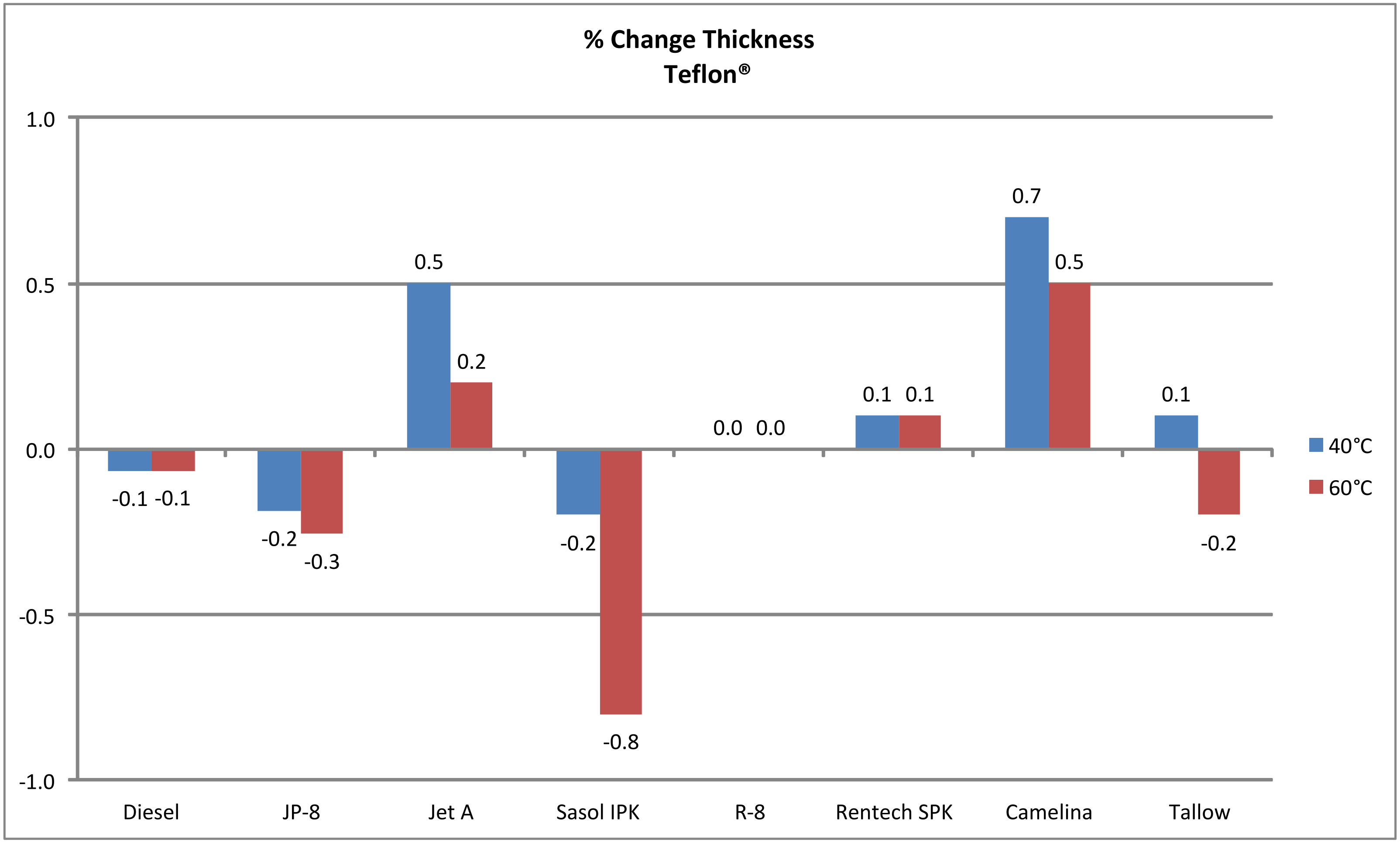

Figure 27. Change in Thickness for Teflon® Samples after Four Weeks

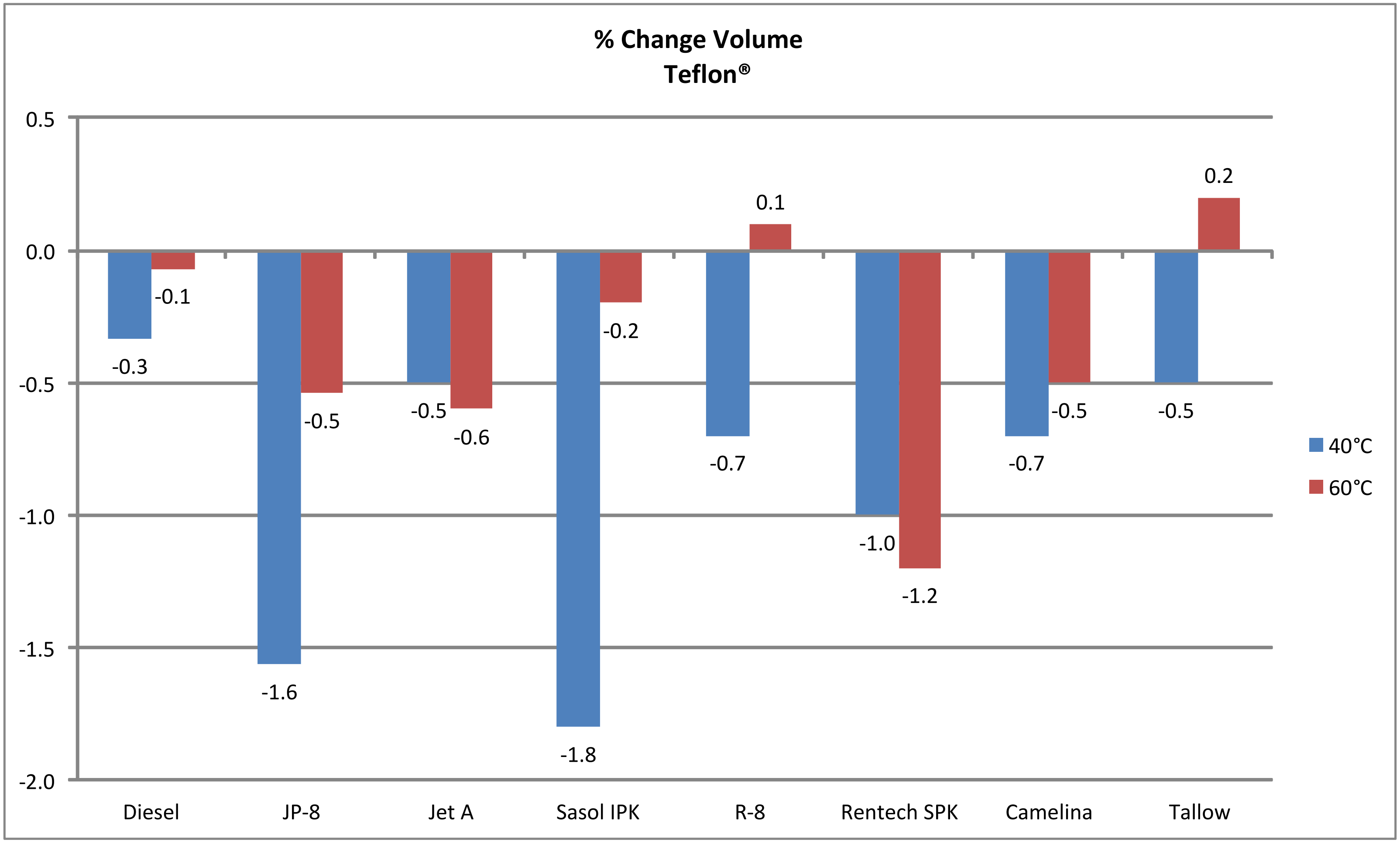

Figure 28. Change in Volume for Teflon® Samples after Four Weeks

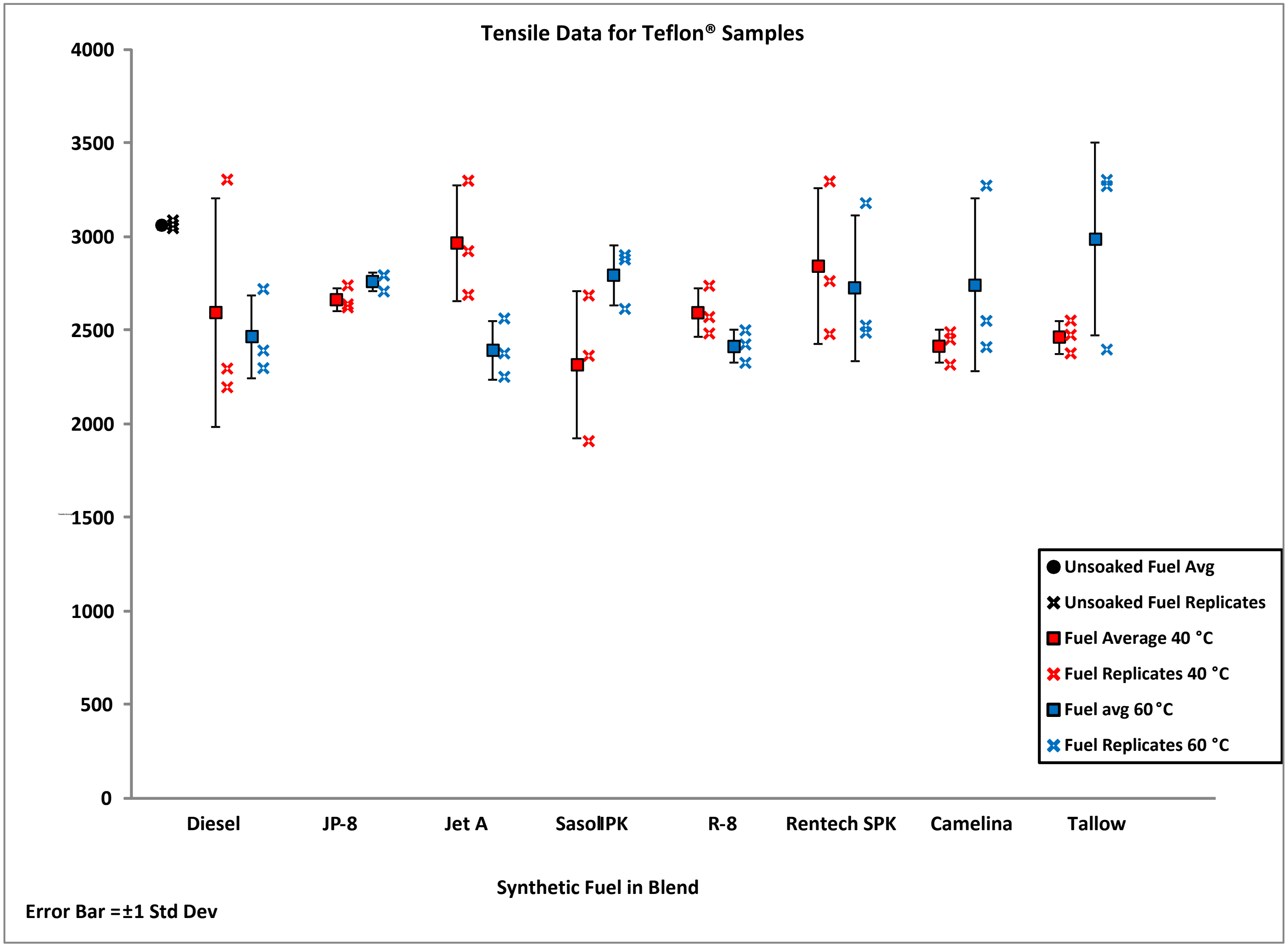

Figure 29. Tensile Strength Data for Teflon® Samples after Four Weeks

3.2 Fuel Switch Tests

The fuel switch loading data indicate that fuel switching resulted in changes to thickness, hardness and volume. The 50/50 alternative fuel blends affected each given material the same way; as observed in the plots, all the fuels followed the same trend line for a given material. The same trend line was observed regardless of the baseline fuel, either diesel or JP-8. The differences that were observed do not seem to be significant (e.g., change in 1 point for shore M hardness), but this should be evaluated for each fuel system.

The tensile data showed that the tensile strength of the O-rings did not change for the 50/50 alternative blends. The small differences observed are within the standard deviation.

3.2.1 Fluorosilicone (Figure 30 to Figure 36)

An overall decrease in hardness and thickness was observed, as well as, an overall increase in volume. The tensile strength data was consistent among the alternative fuel blends.

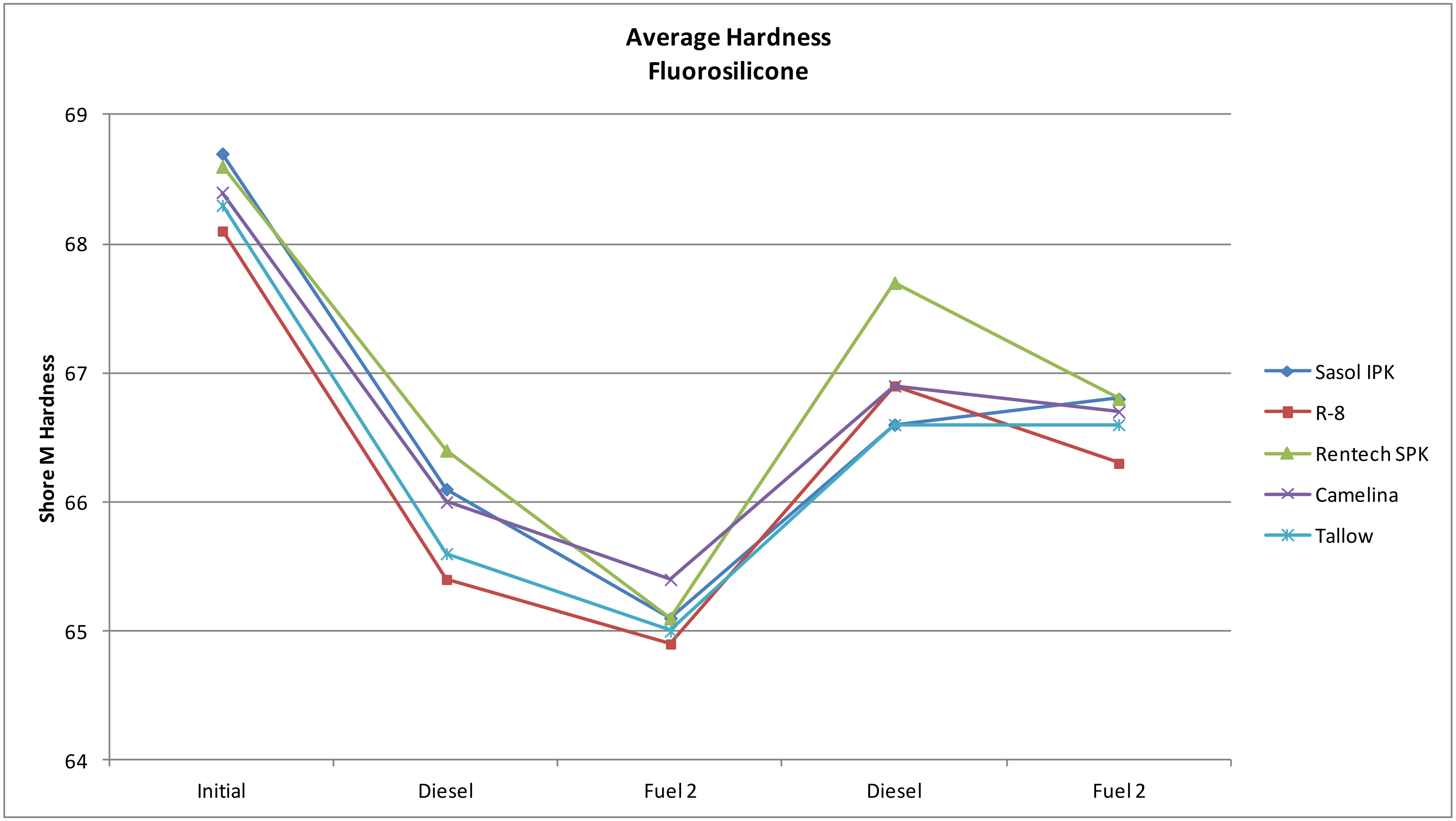

Figure 30. Hardness Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with Diesel as The Baseline Fuel

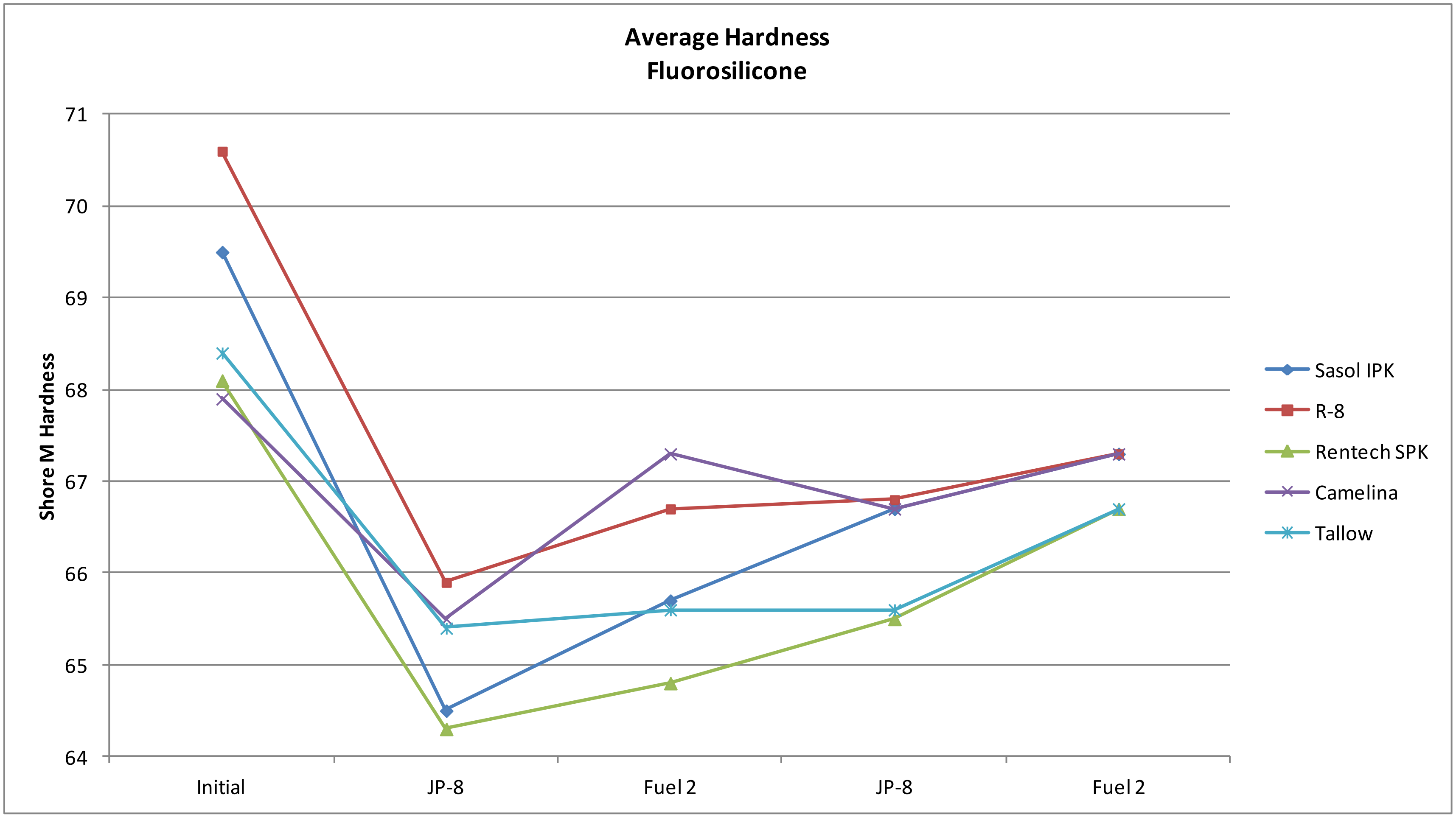

Figure 31. Hardness Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

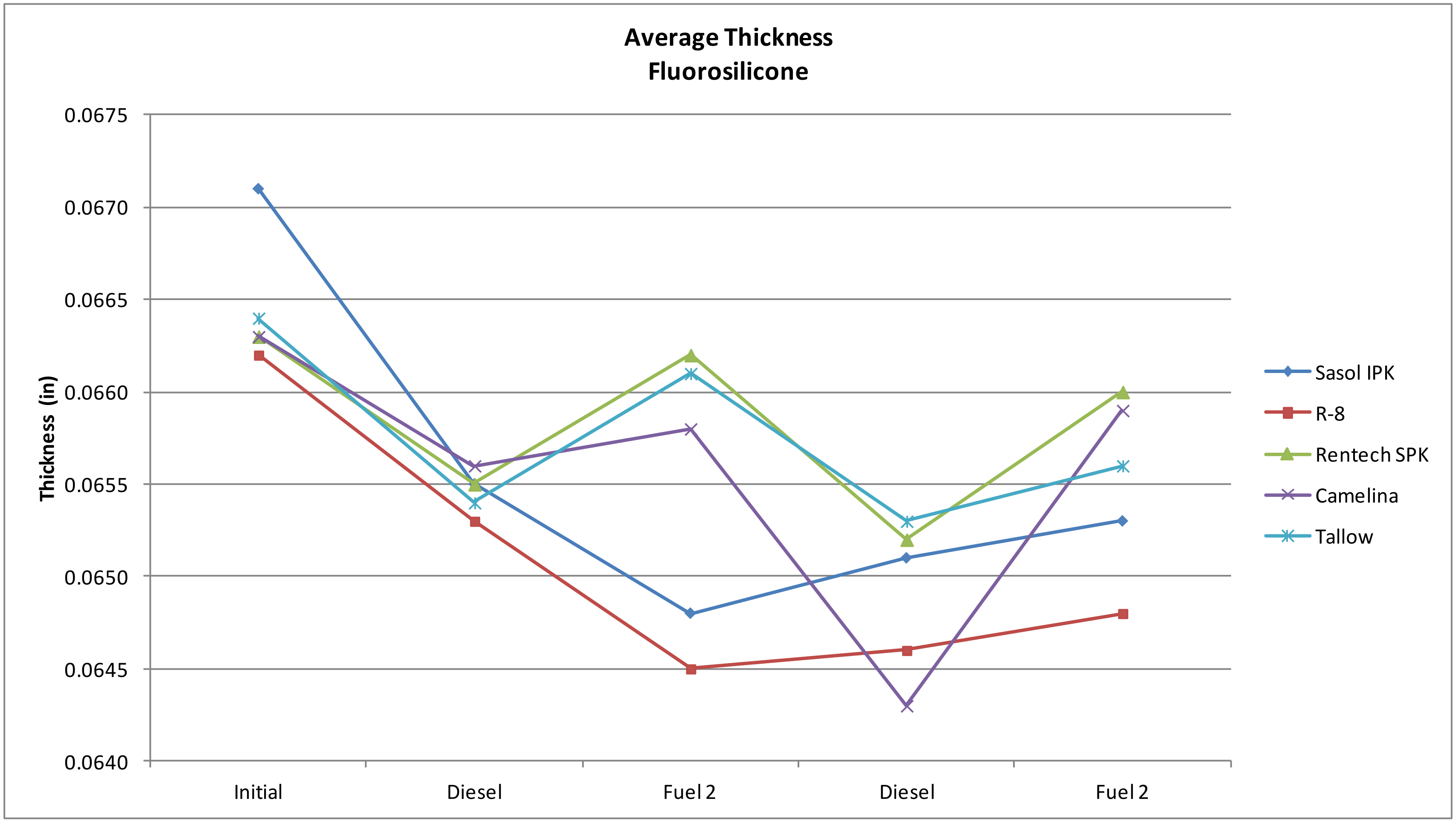

Figure 32. Thickness Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

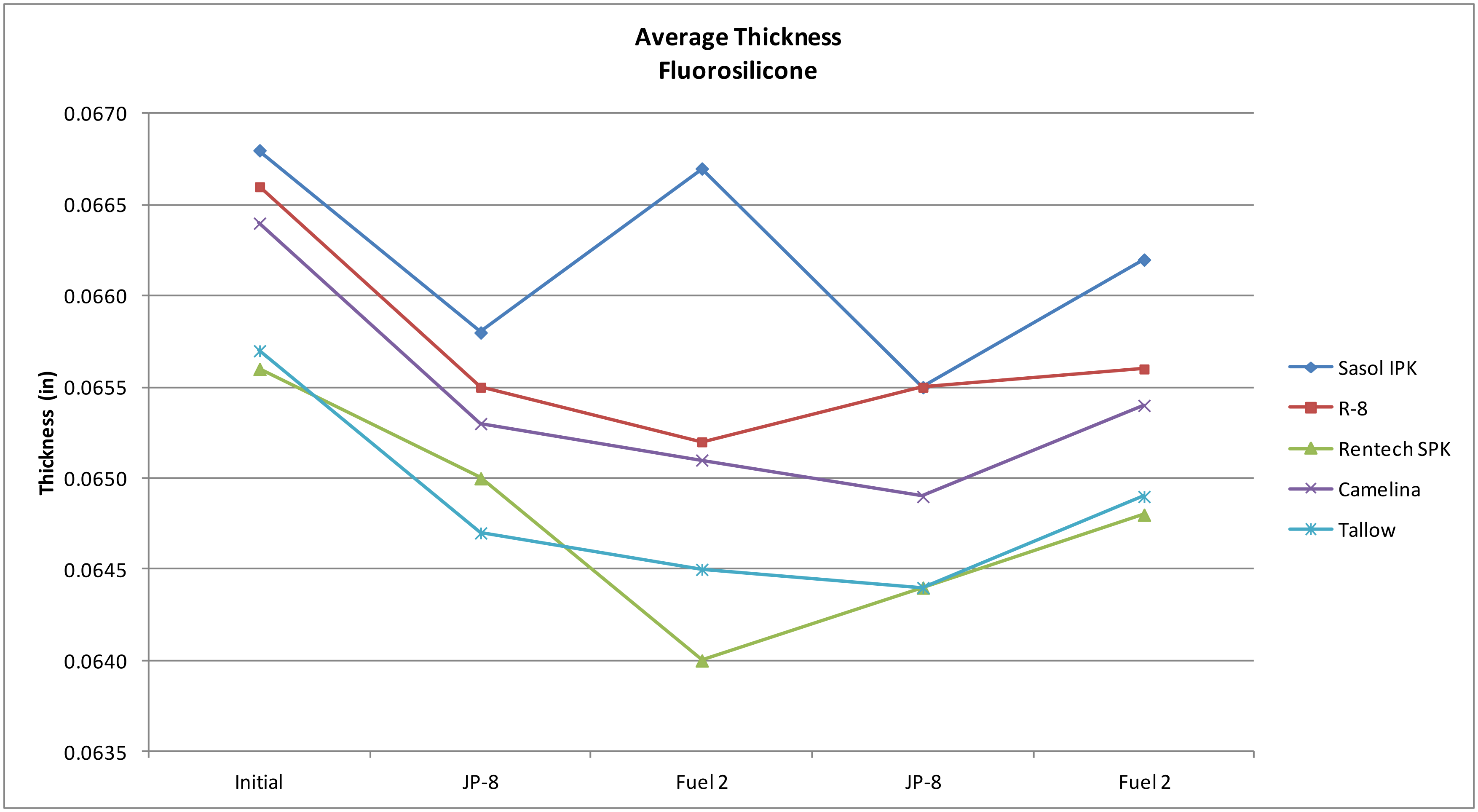

Figure 33. Thickness Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

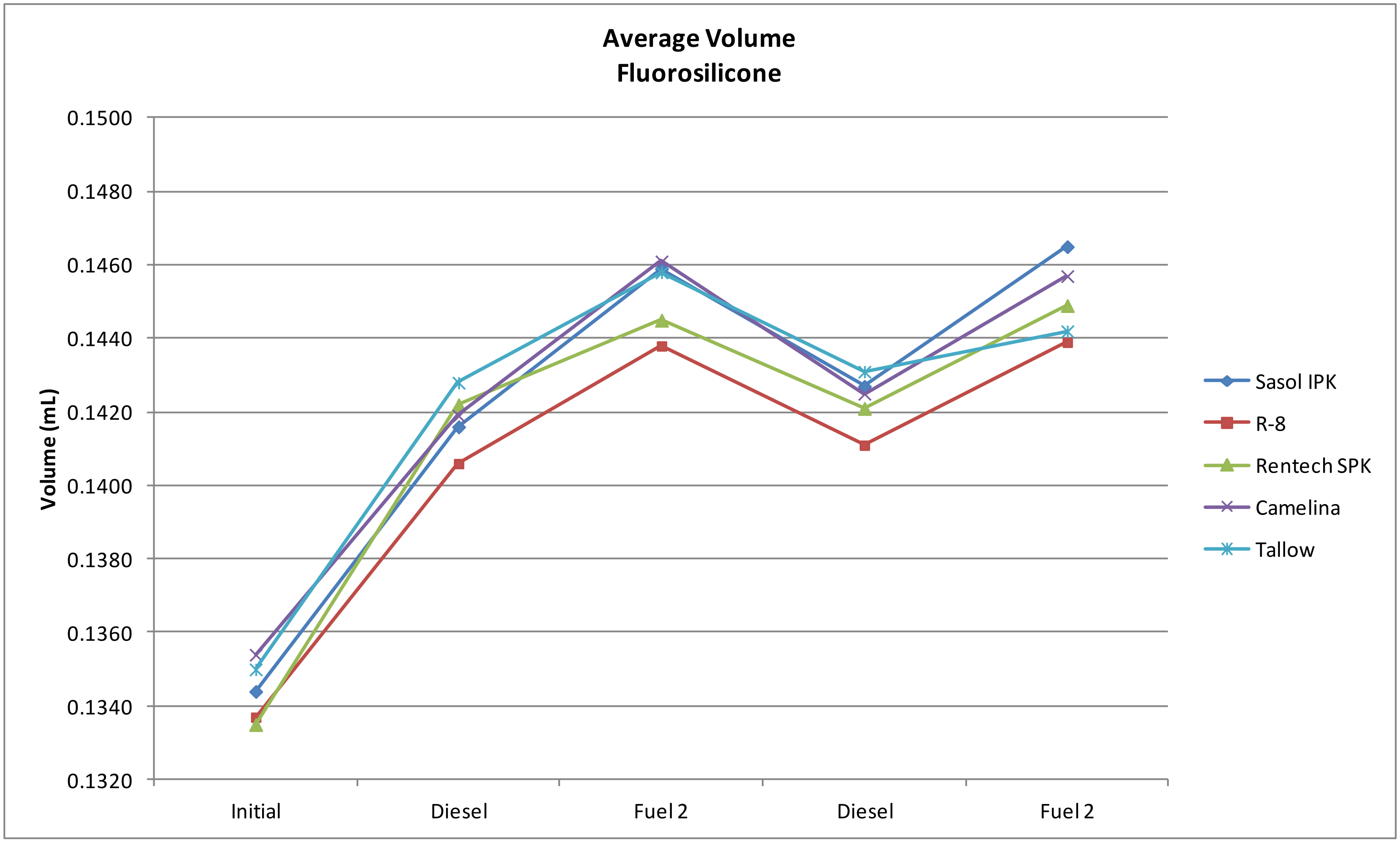

Figure 34. Volume Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

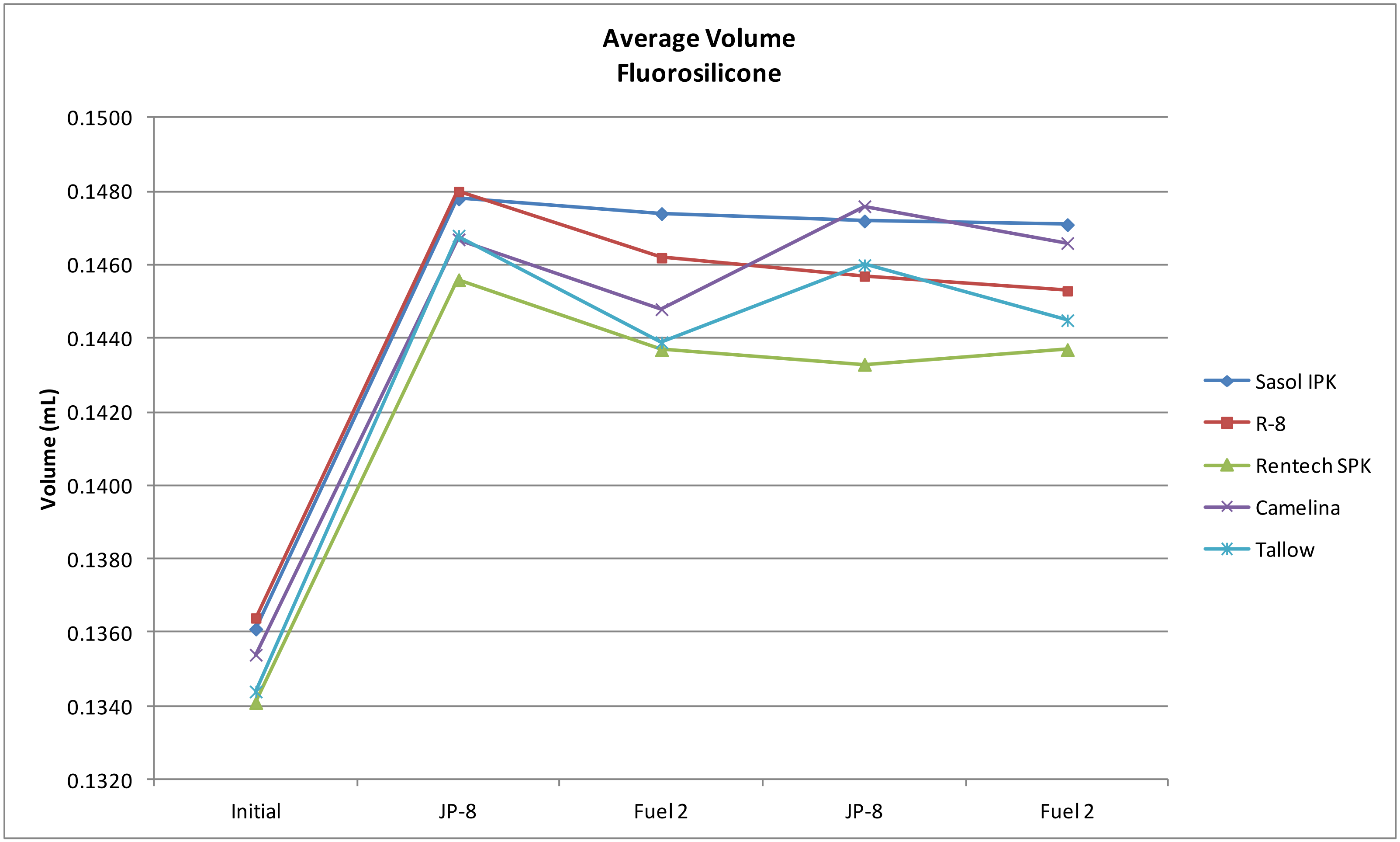

Figure 35. Volume Data for Fluorosilicone Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

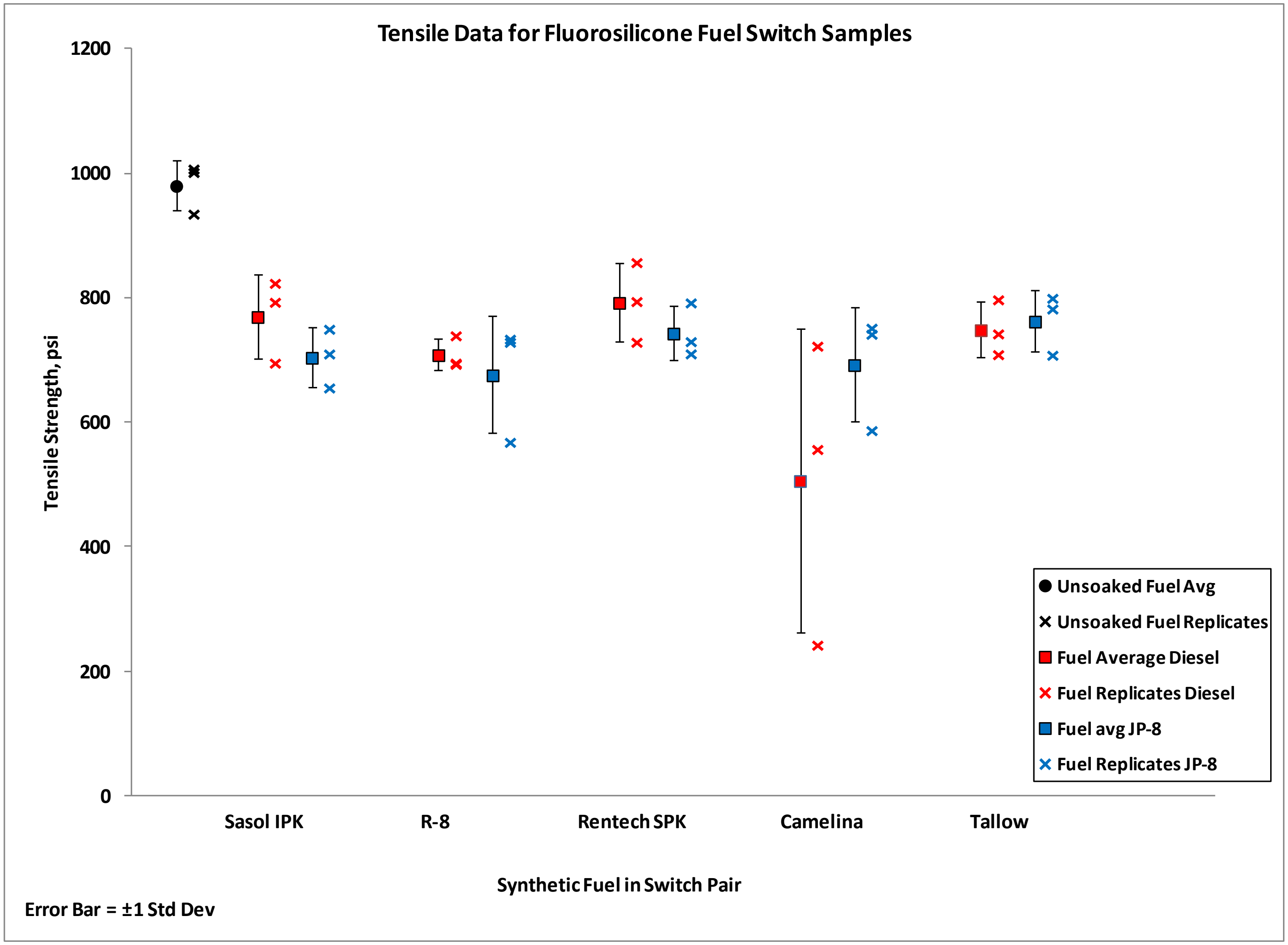

Figure 36. Tensile Strength Data for Fluorosilicone Switch-Loading Samples after 8 Weeks

3.2.2 Nitrile (Figure 37 to Figure 43)

An overall increase in both hardness and volume was observed. The thickness stayed nearly constant (e.g., 0.0010 in change). The tensile strength data were consistent among the alternative fuel blends.

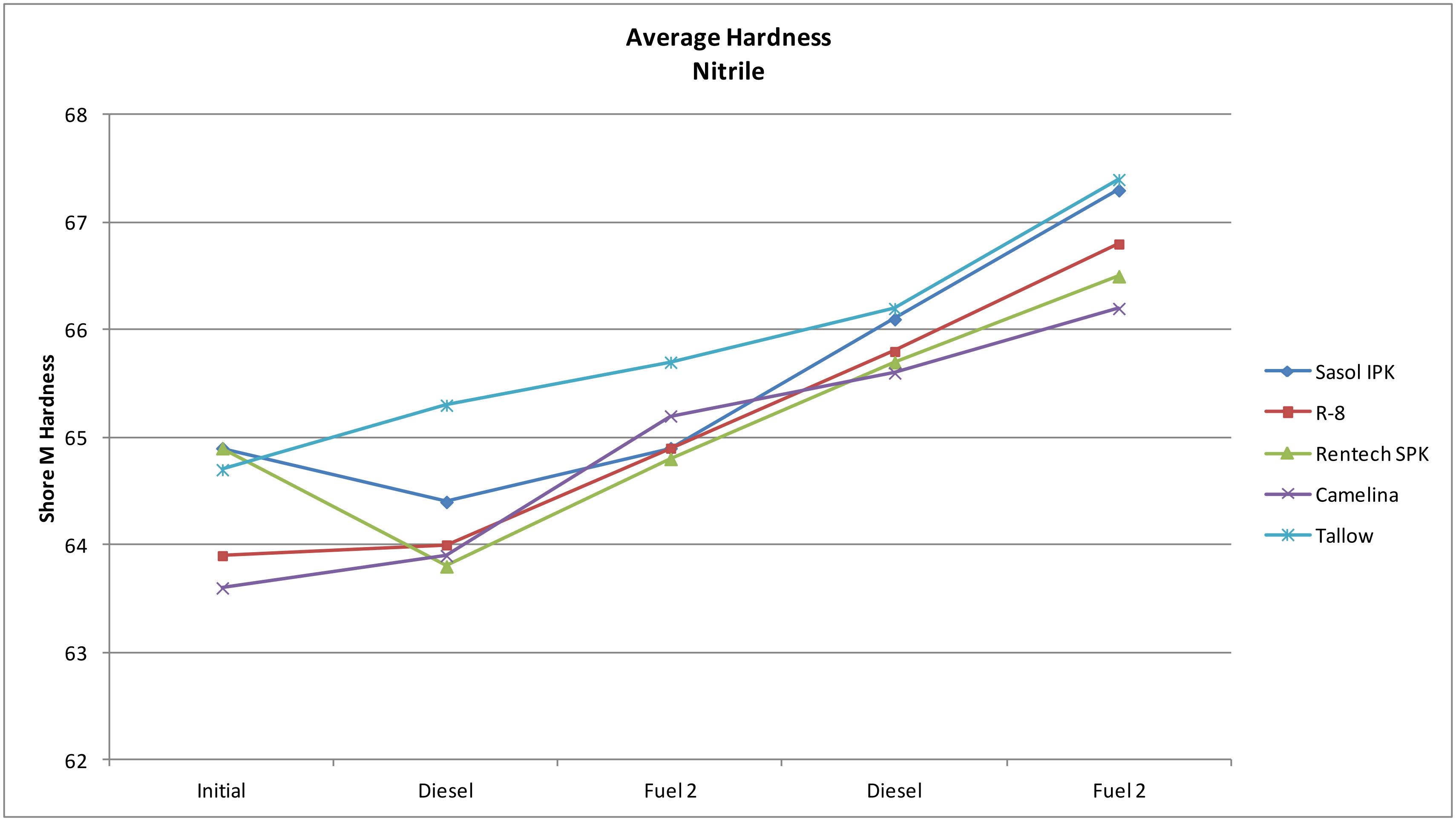

Figure 37. Hardness Data for Nitrile Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

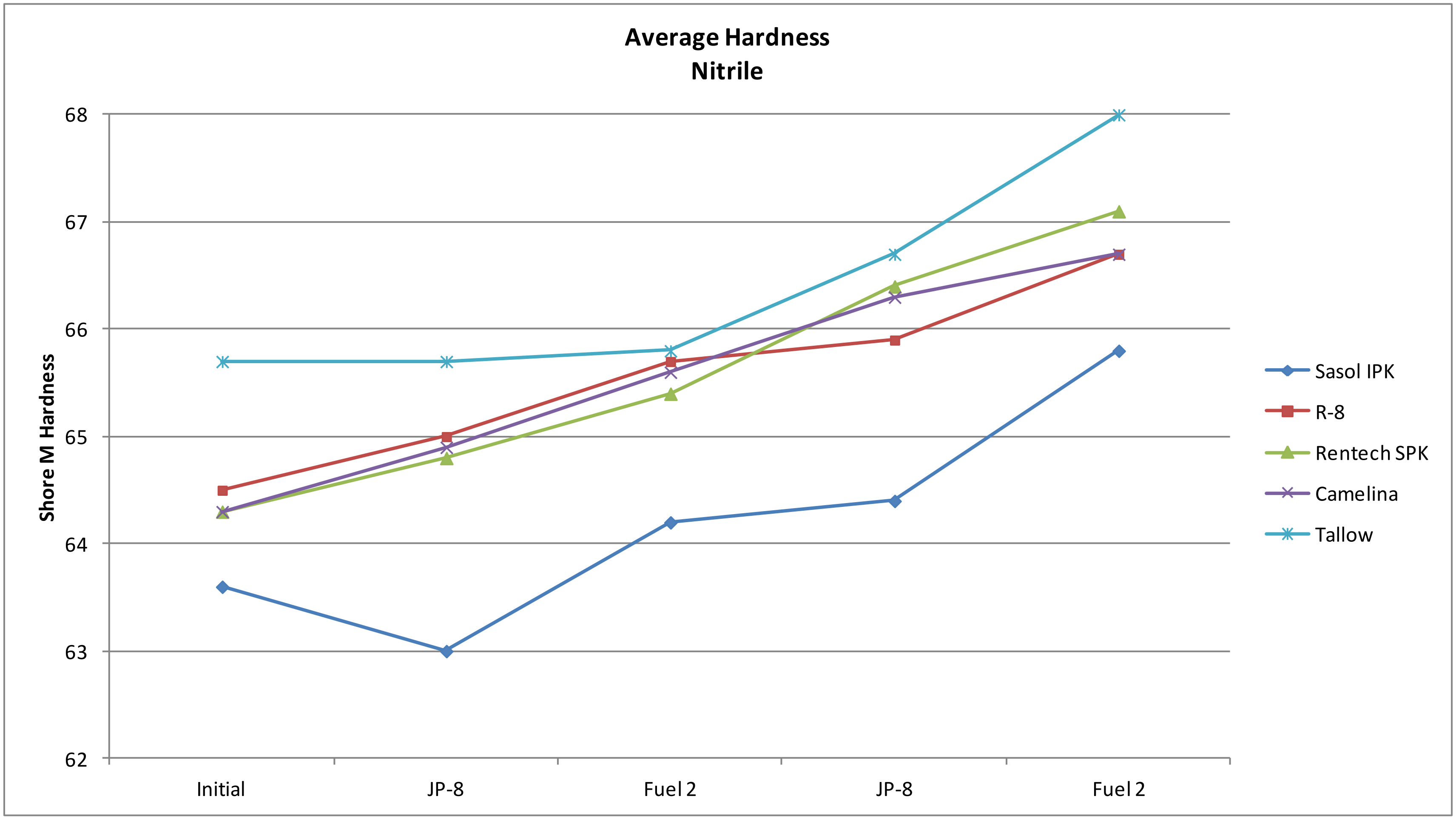

Figure 38. Hardness Data for Nitrile Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

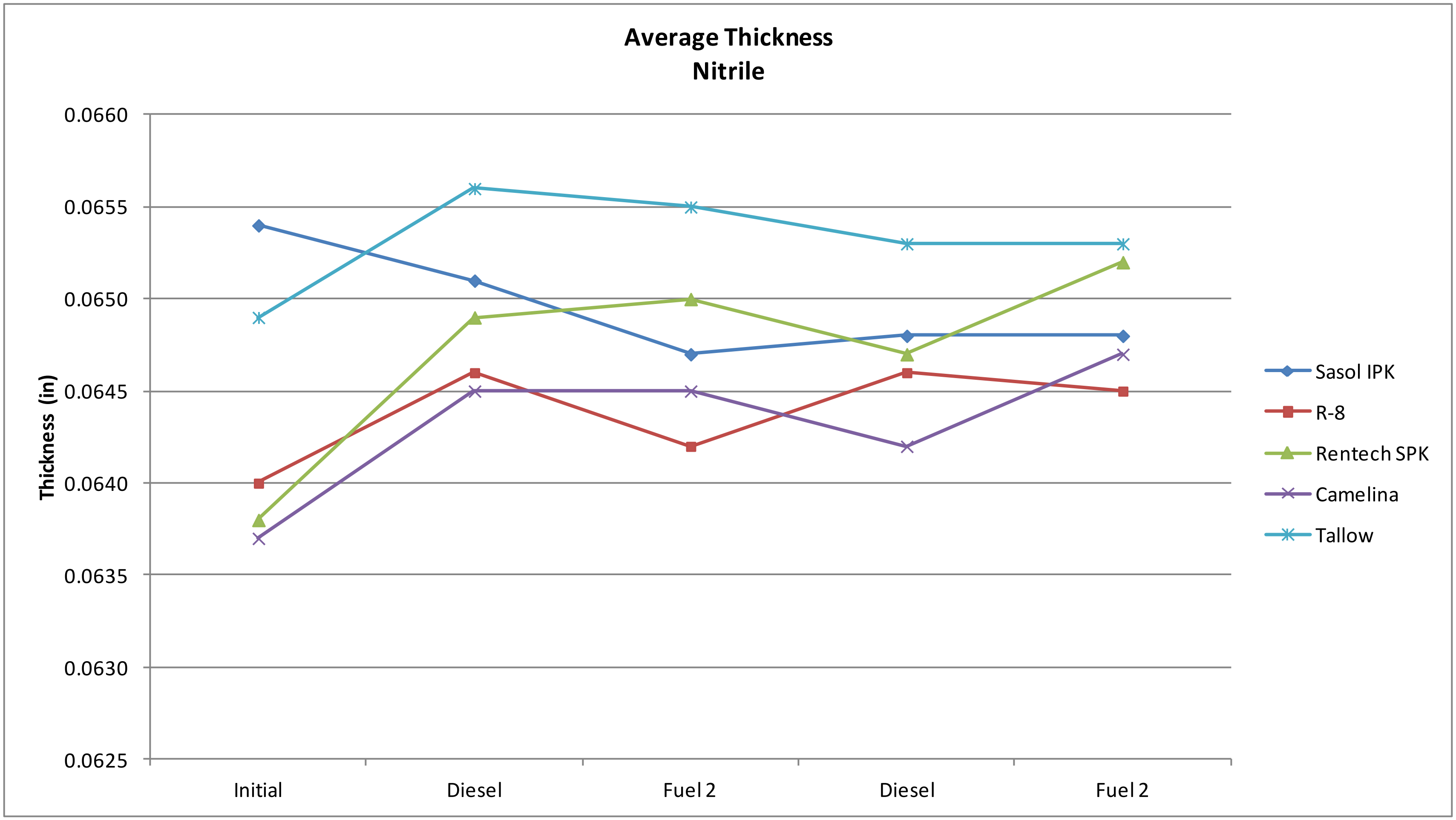

Figure 39. Thickness Data for Nitrile Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

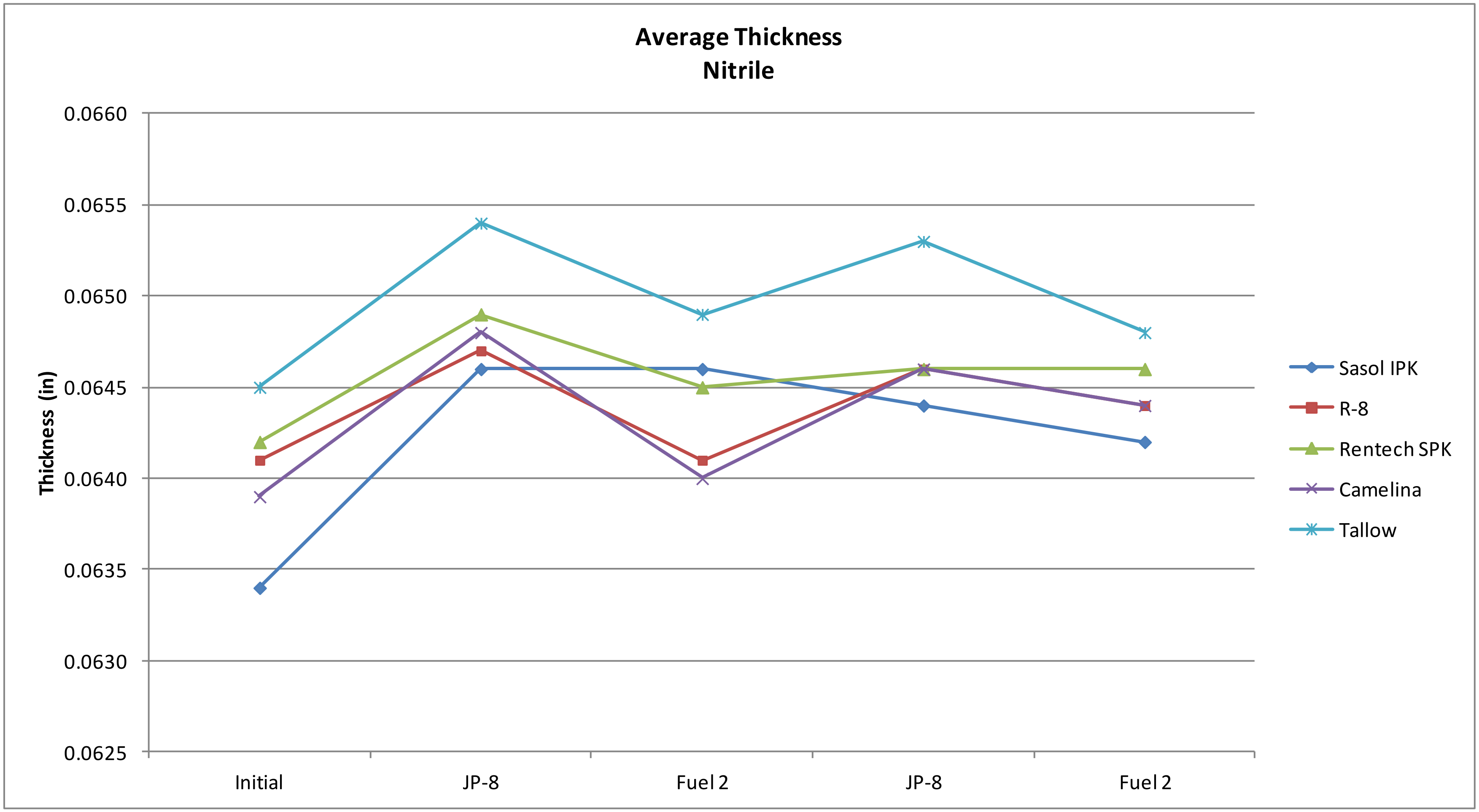

Figure 40. Thickness Data for Nitrile Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

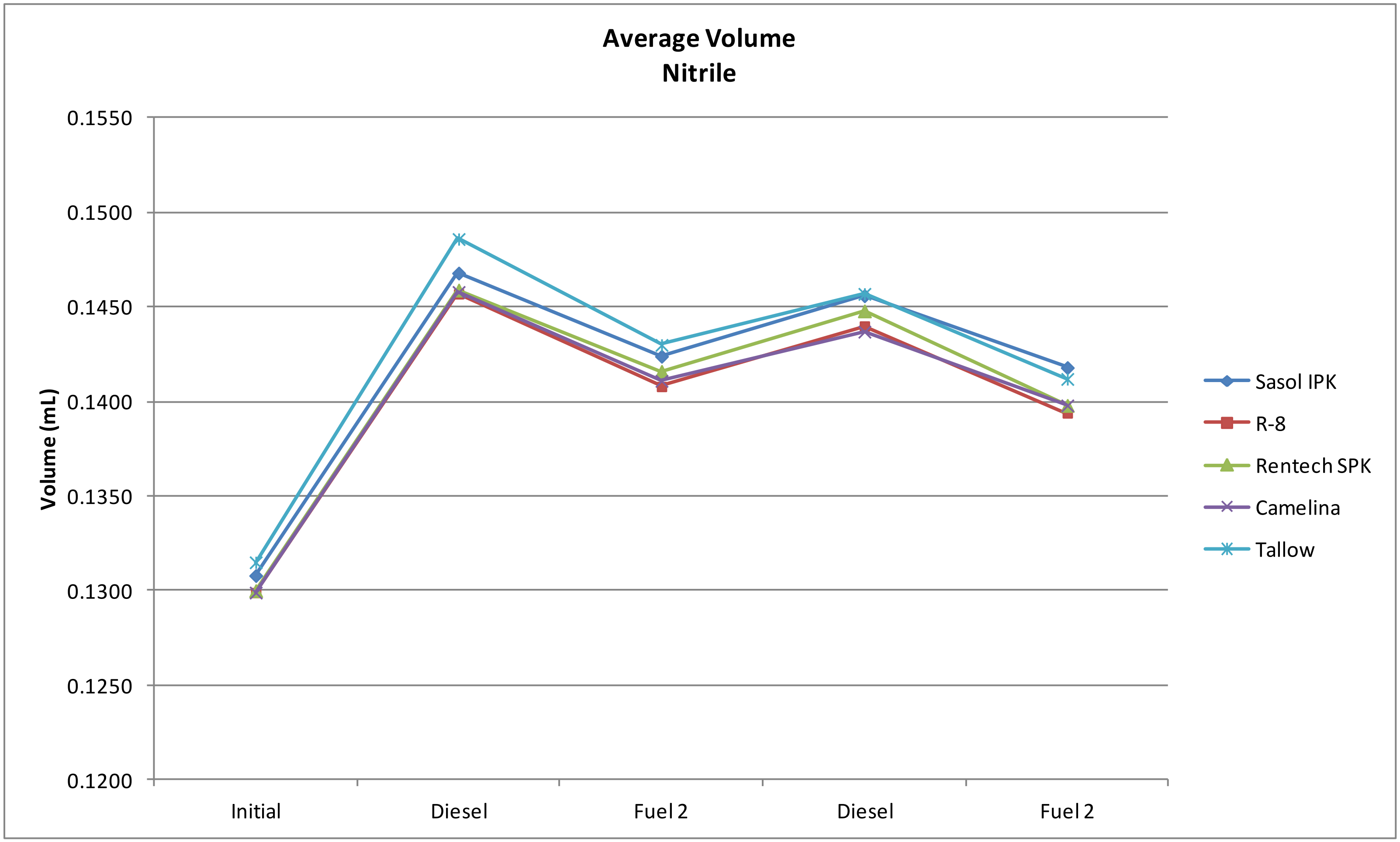

Figure 41. Volume Data for Nitrile Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

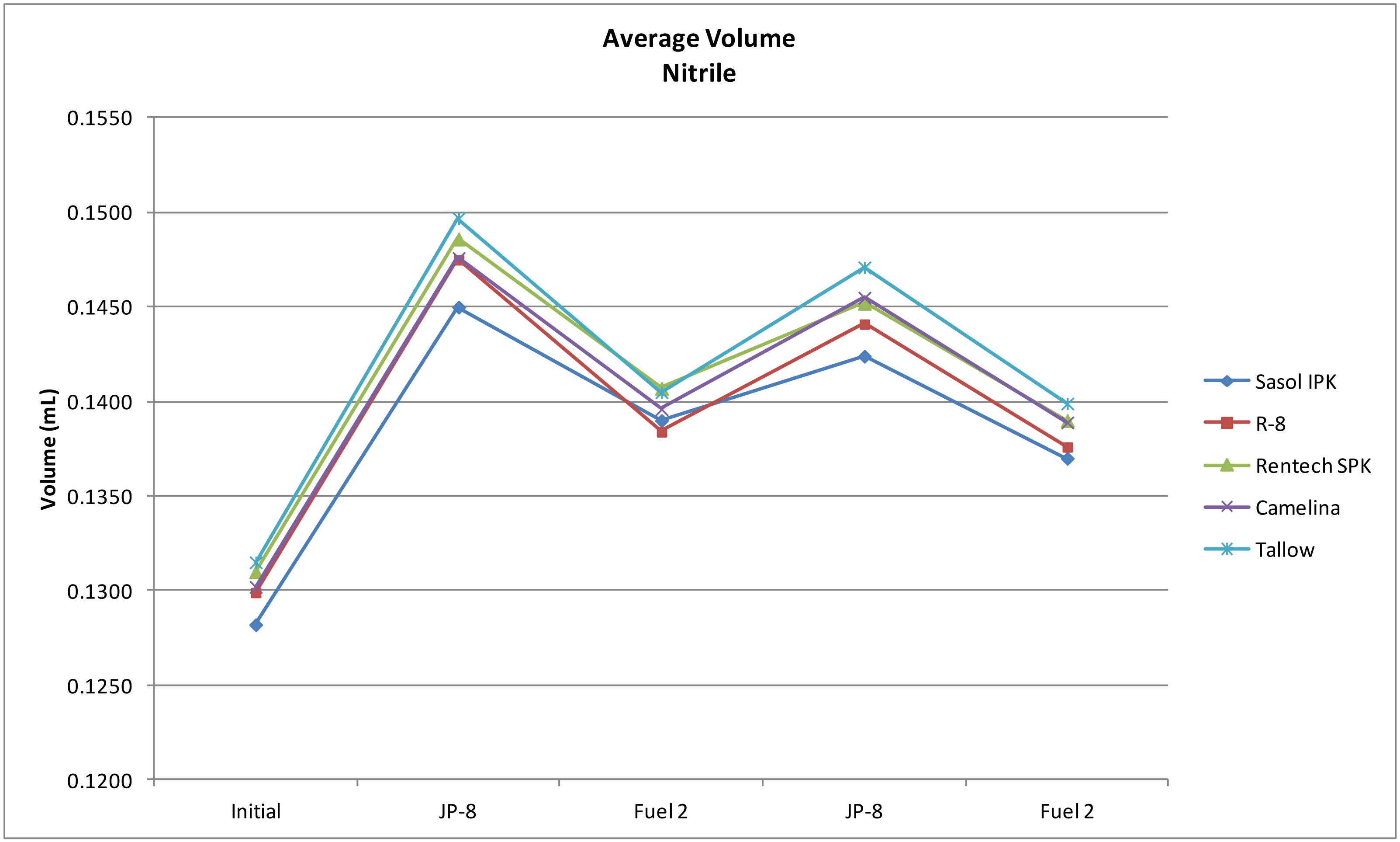

Figure 42. Volume Data for Nitrile Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

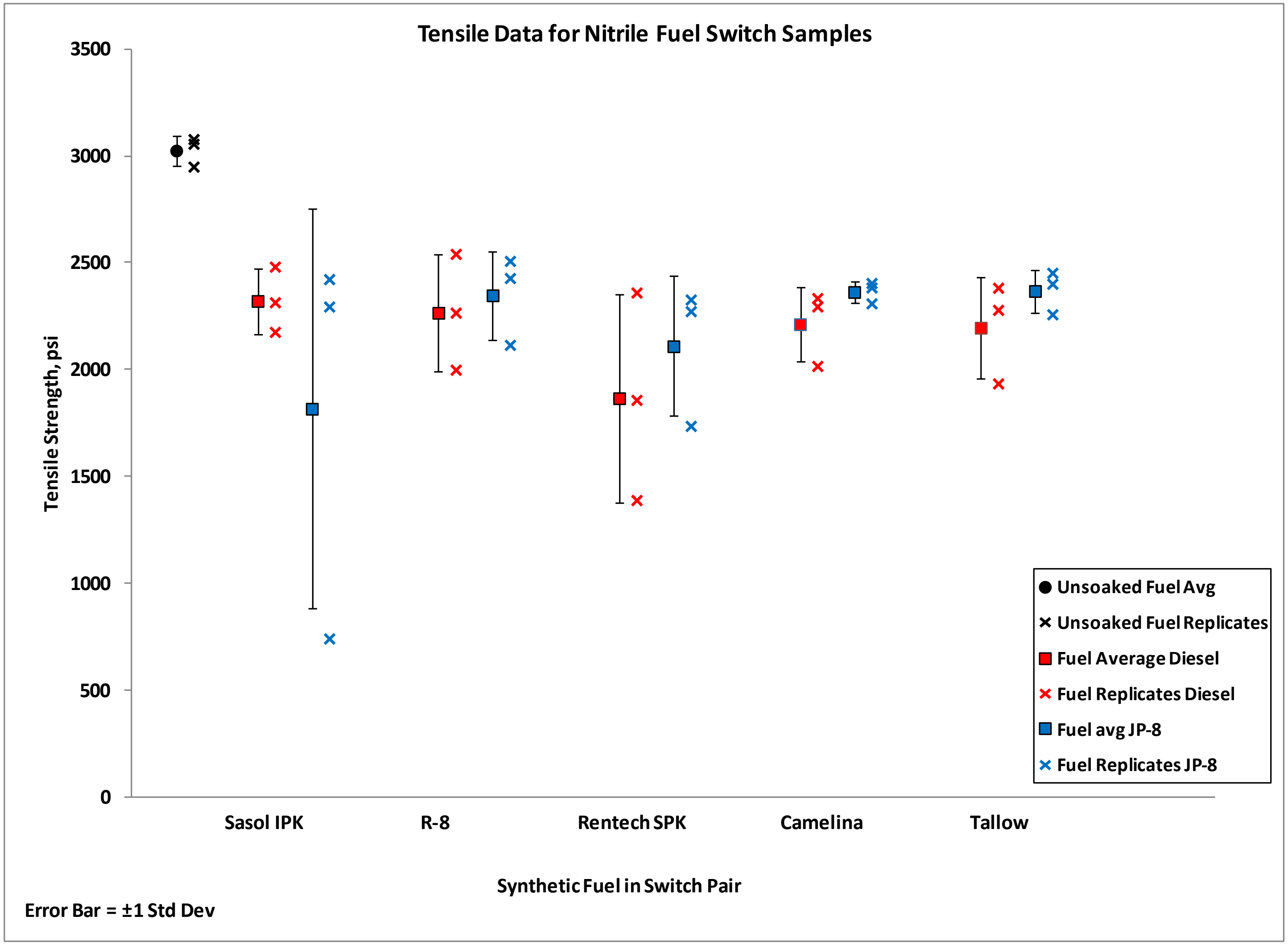

Figure 43. Tensile Strength Data for Nitrile Switch-Loading Samples after 8 Weeks

3.2.3 Polyurethane (Figure 44 to Figure 50)

An overall decrease in hardness was observed, as well as an increase in thickness and volume. The tensile strength data were consistent among the alternative fuel blends.

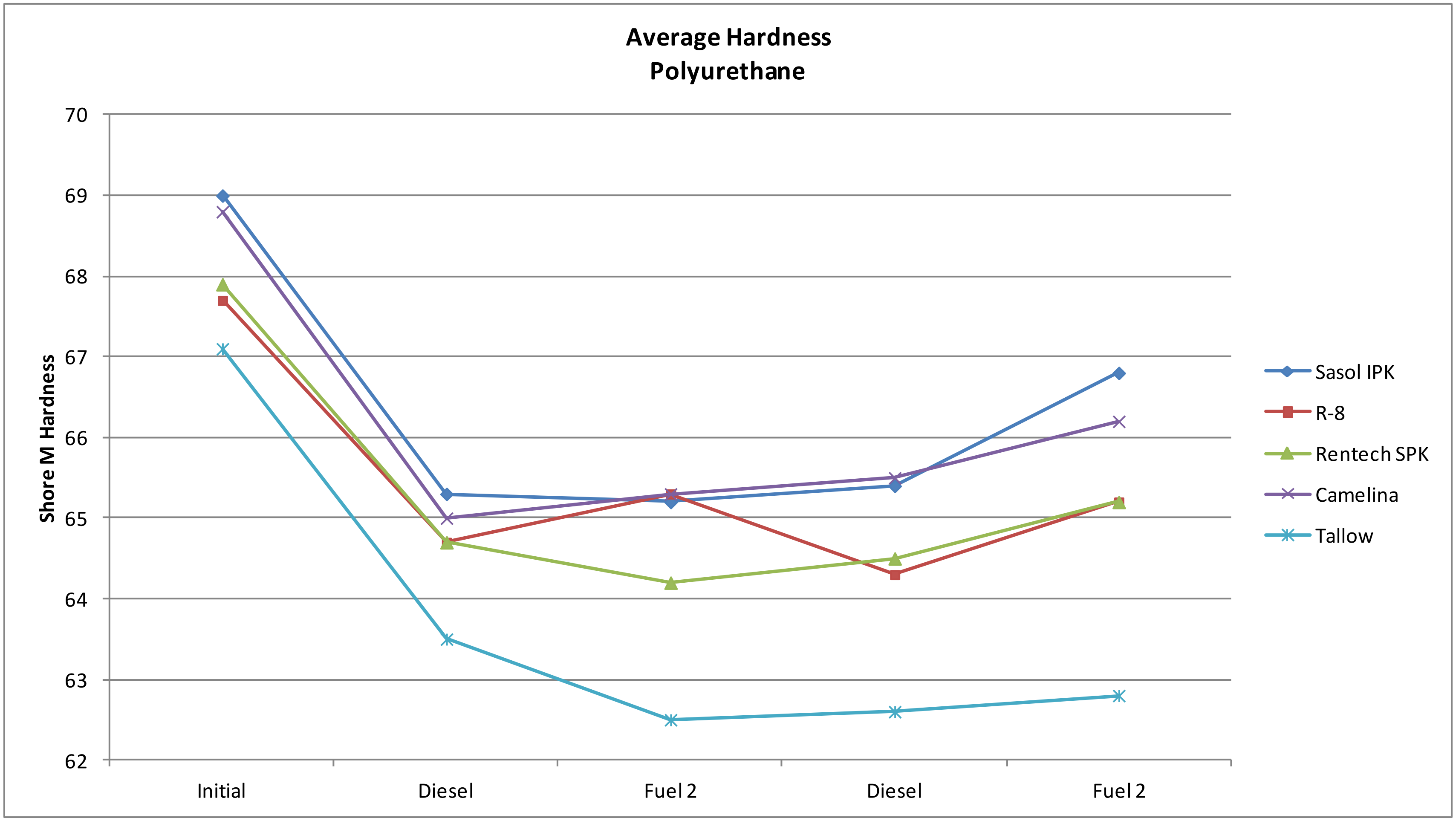

Figure 44. Hardness Data for Polyurethane Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

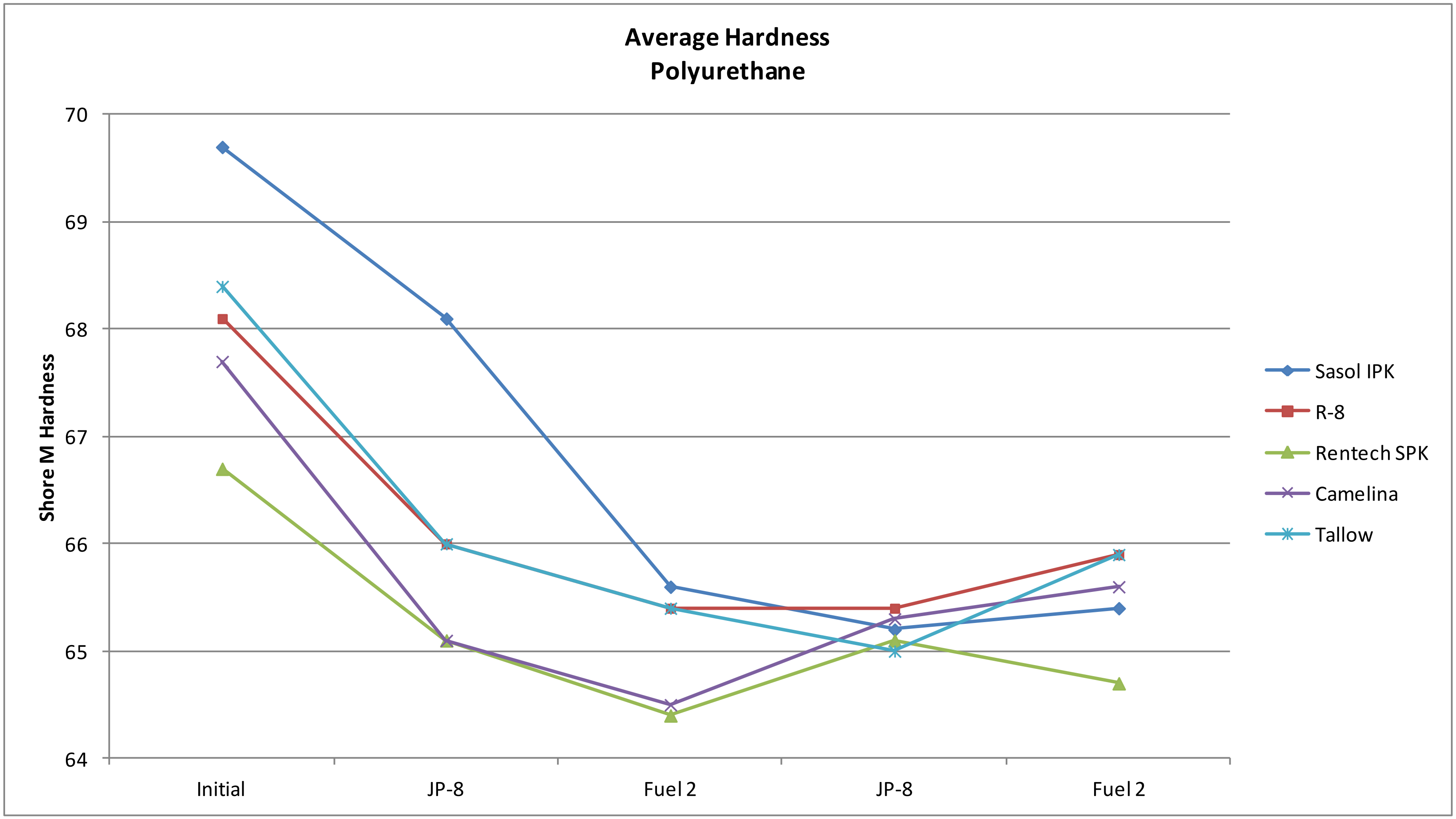

Figure 45. Hardness Data for Polyurethane Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

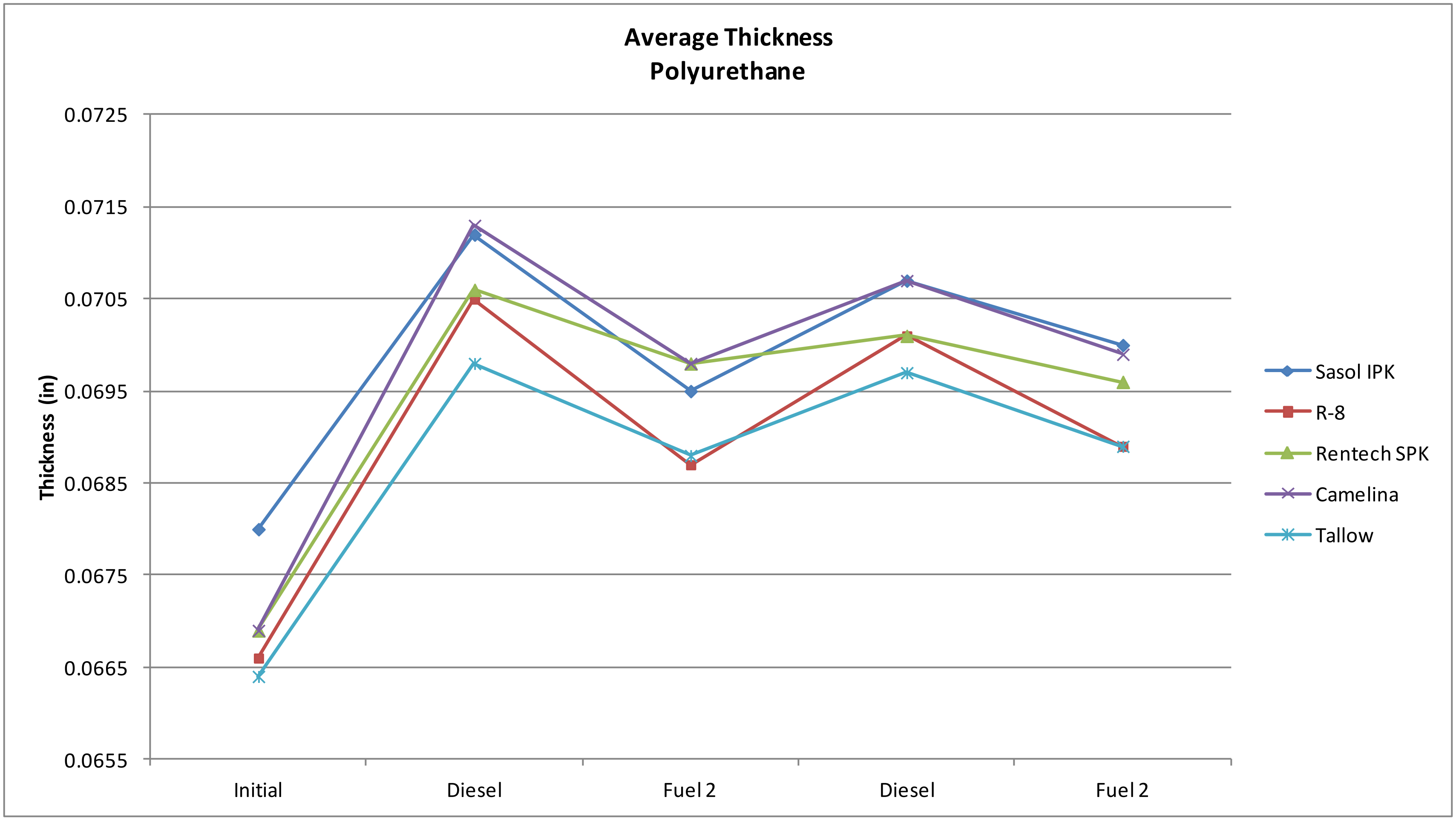

Figure 46. Thickness Data for Polyurethane Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

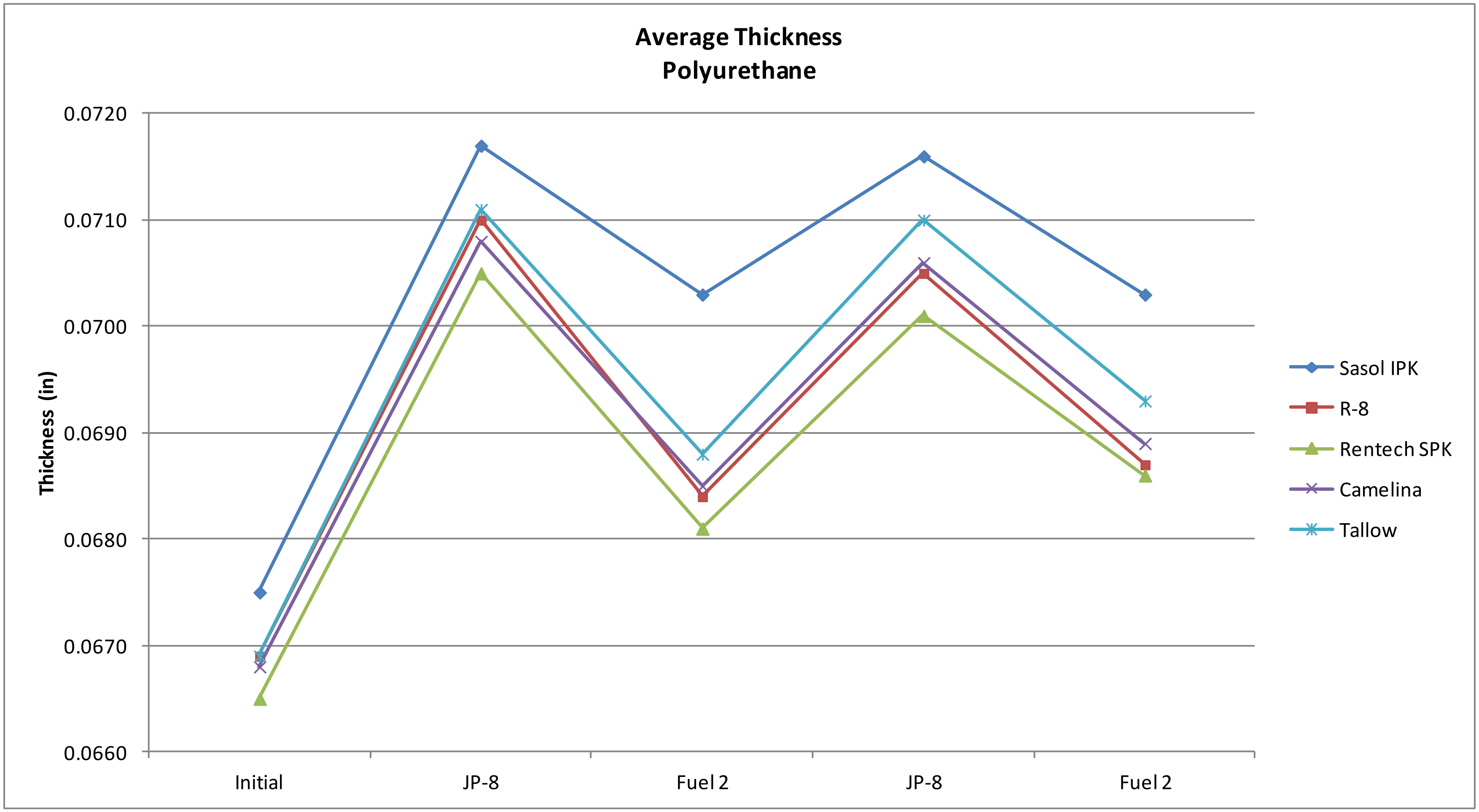

Figure 47. Thickness Data for Polyurethane Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

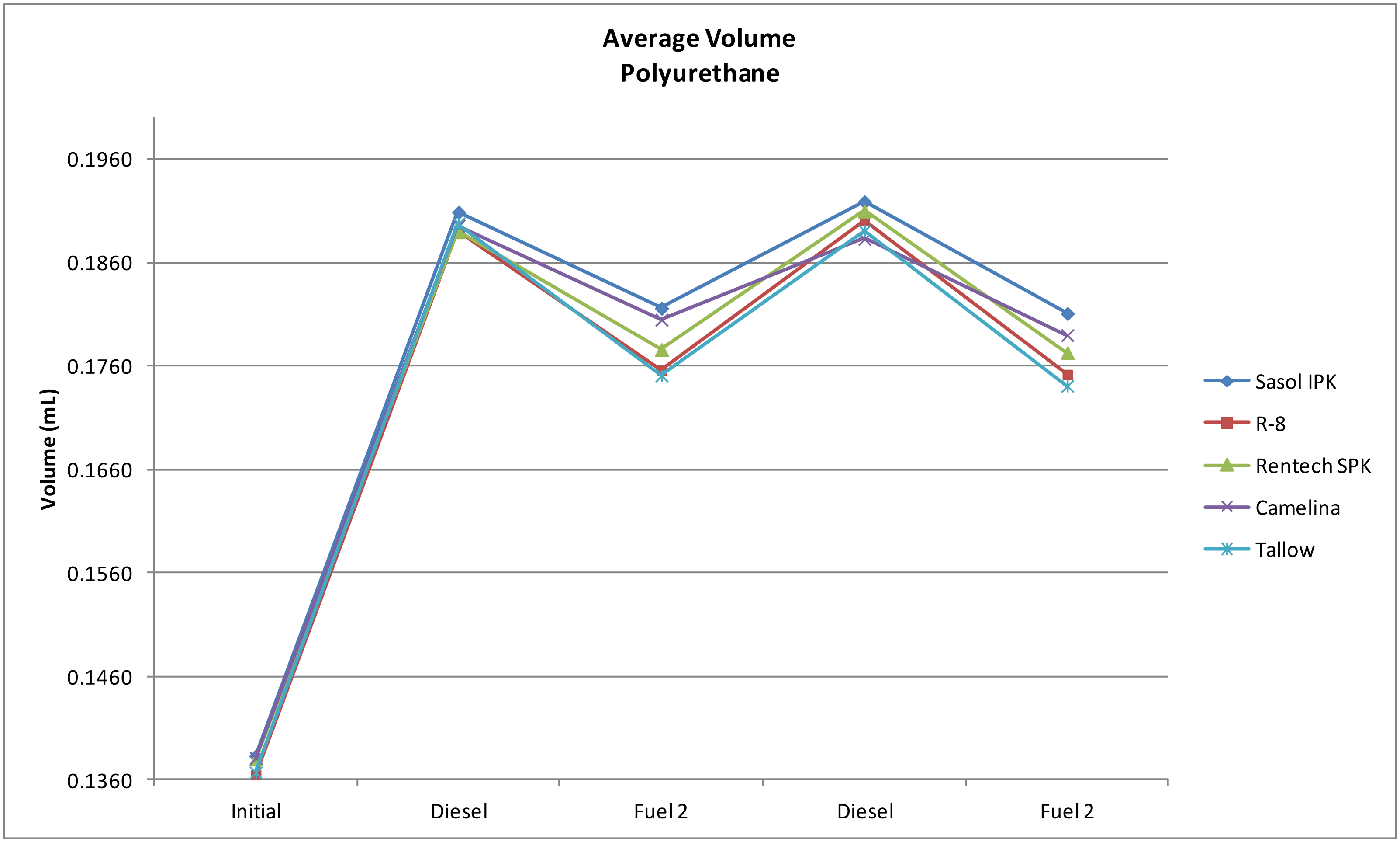

Figure 48. Volume Data for Polyurethane Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

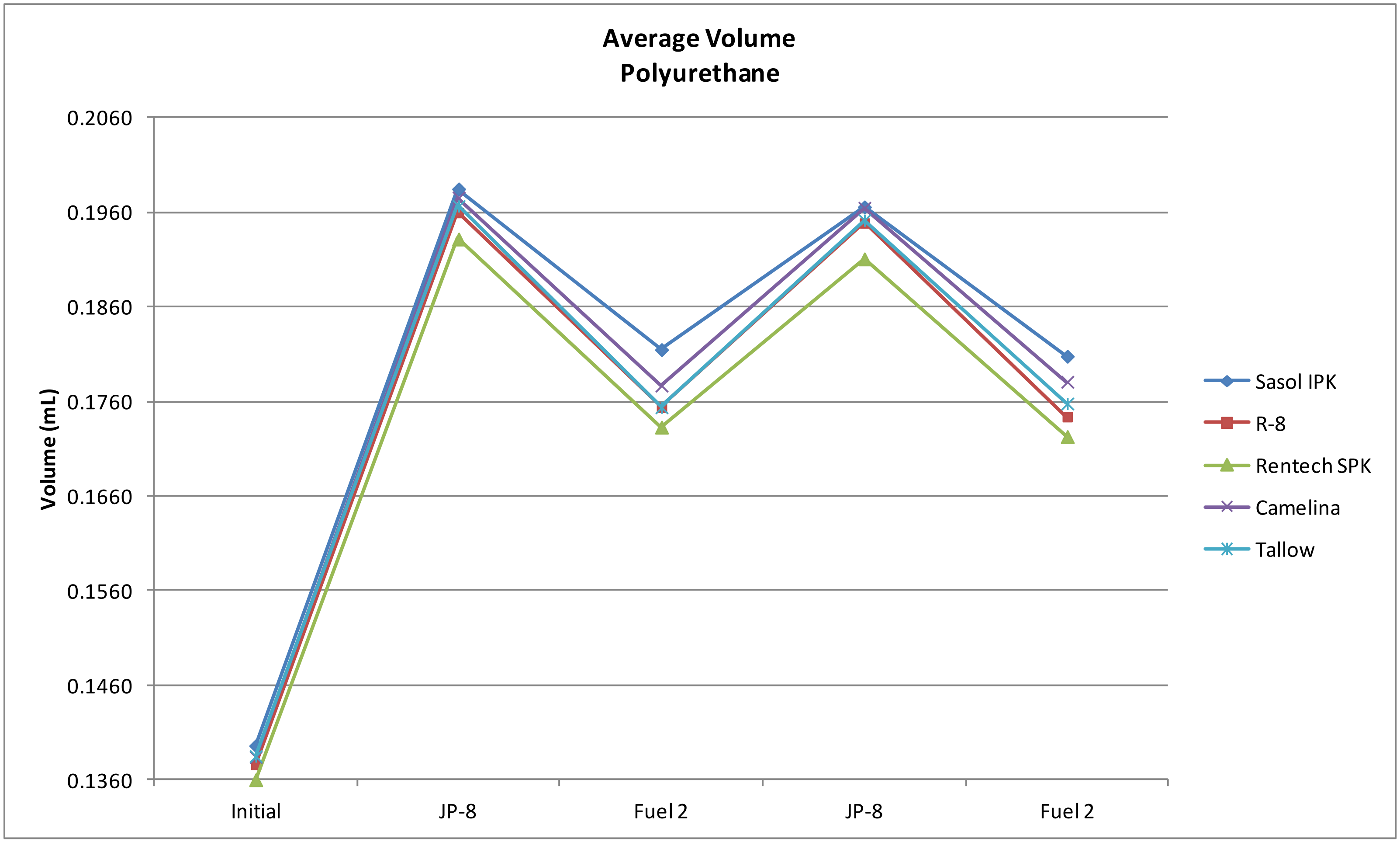

Figure 49. Volume Data for Polyurethane Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

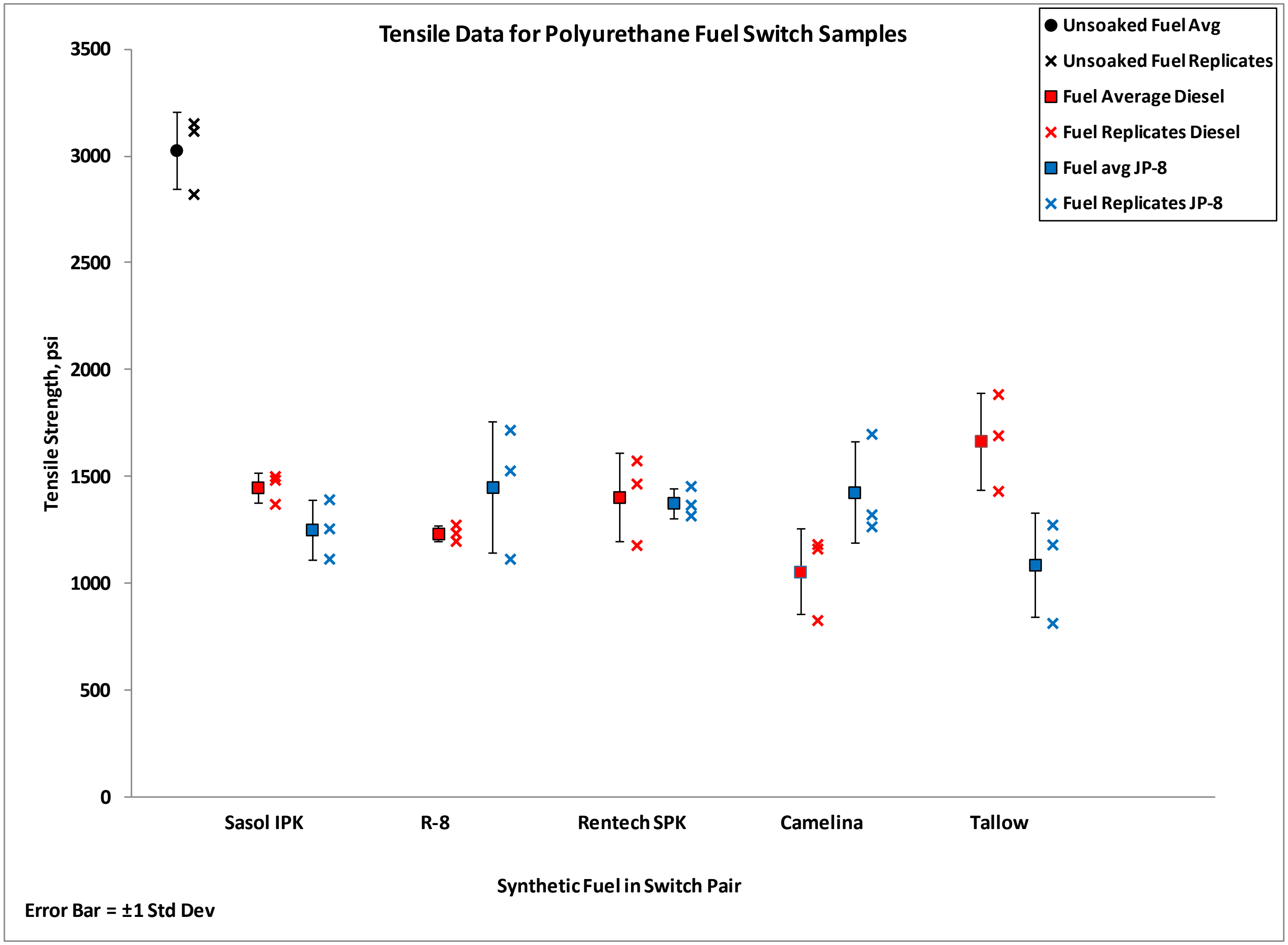

Figure 50. Tensile Strength Data for Polyurethane Switch-Loading Samples after 8 Weeks

3.2.4 Viton® (Figure 51 to Figure 57)

An overall increase in both hardness and volume was observed. The thickness remained fairly constant (e.g., 0.0004 in change). The tensile strength data were consistent among the alternative fuel blends.

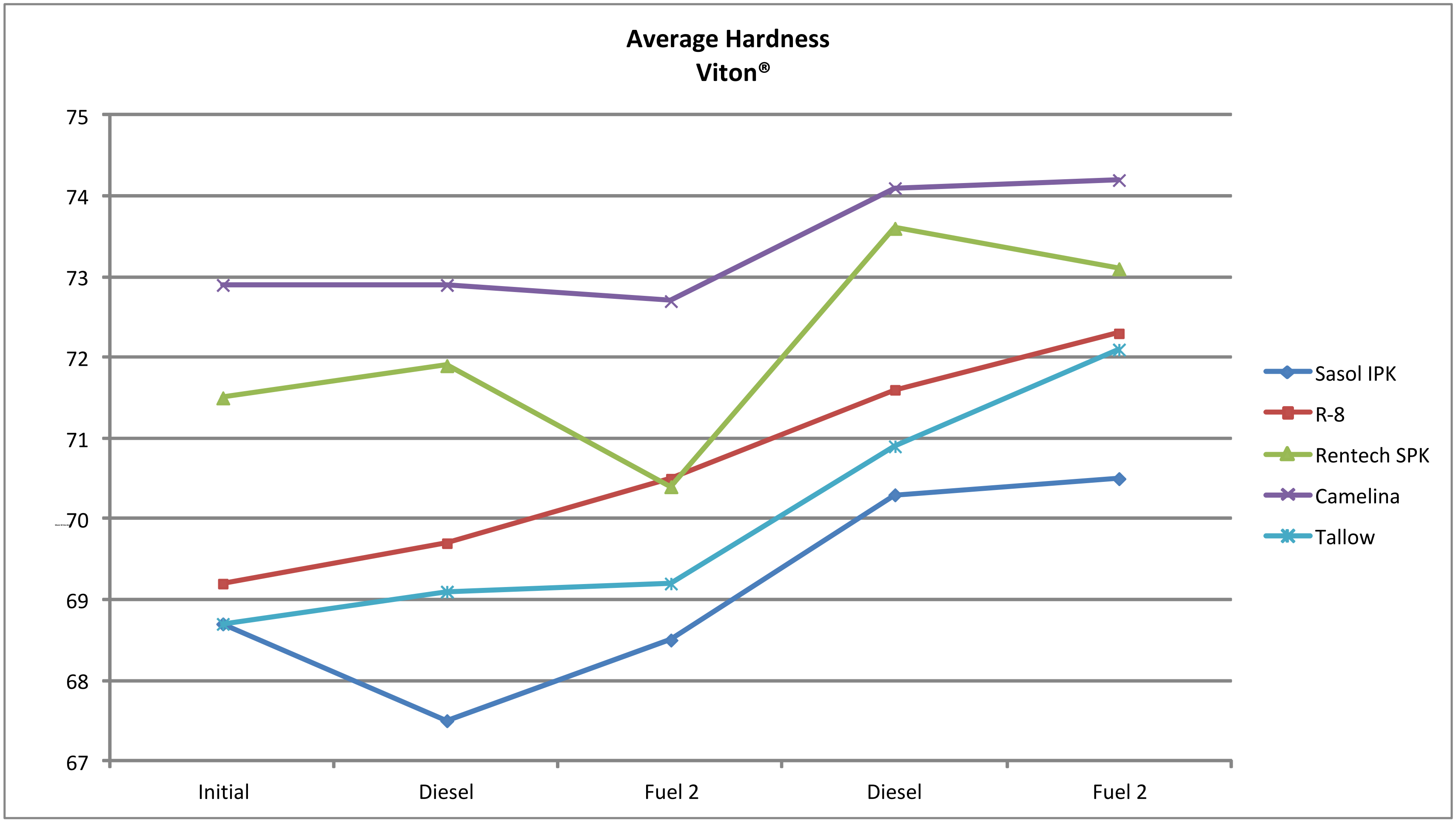

Figure 51. Hardness Data for Viton® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

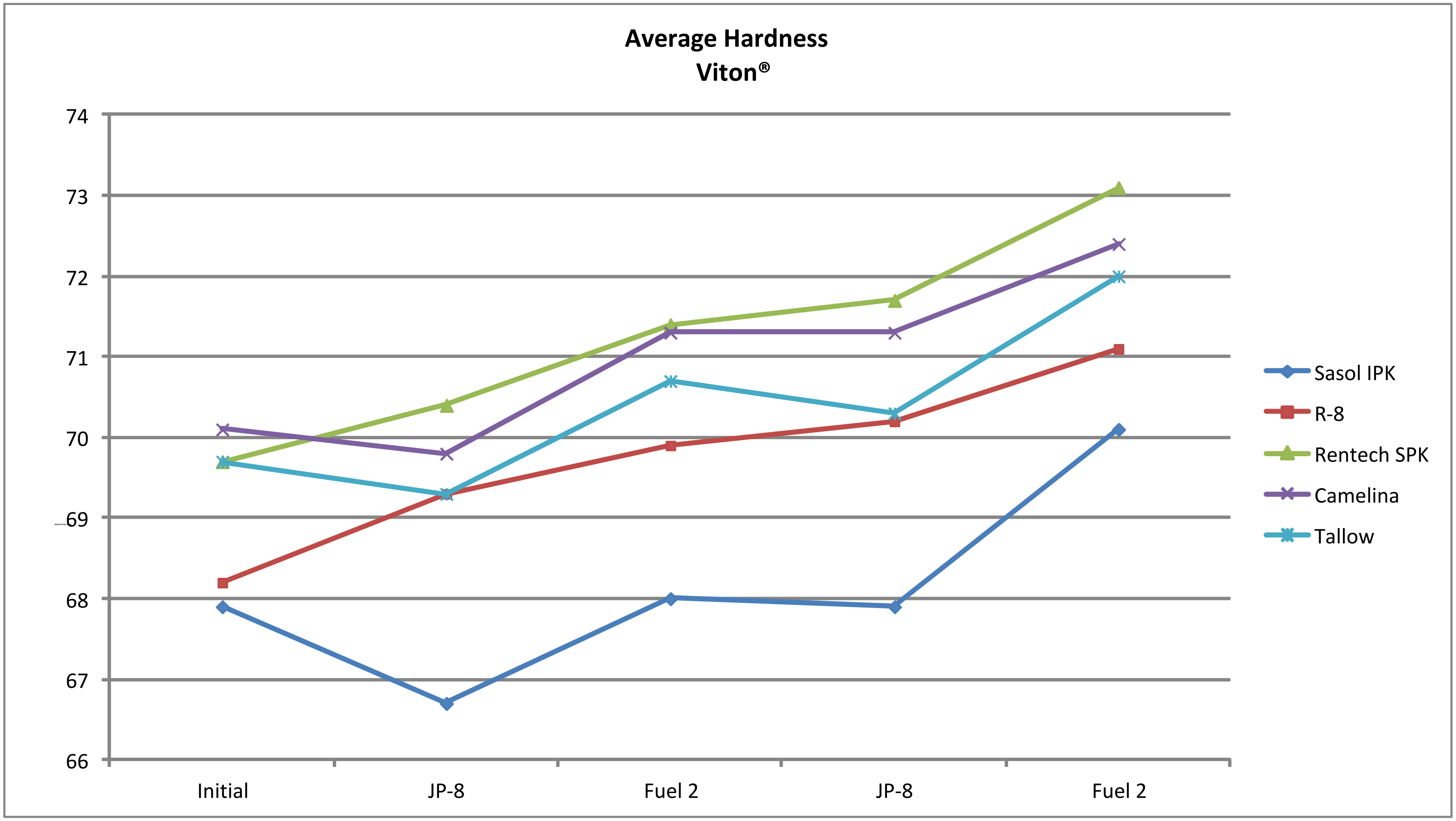

Figure 52. Hardness Data for Viton® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

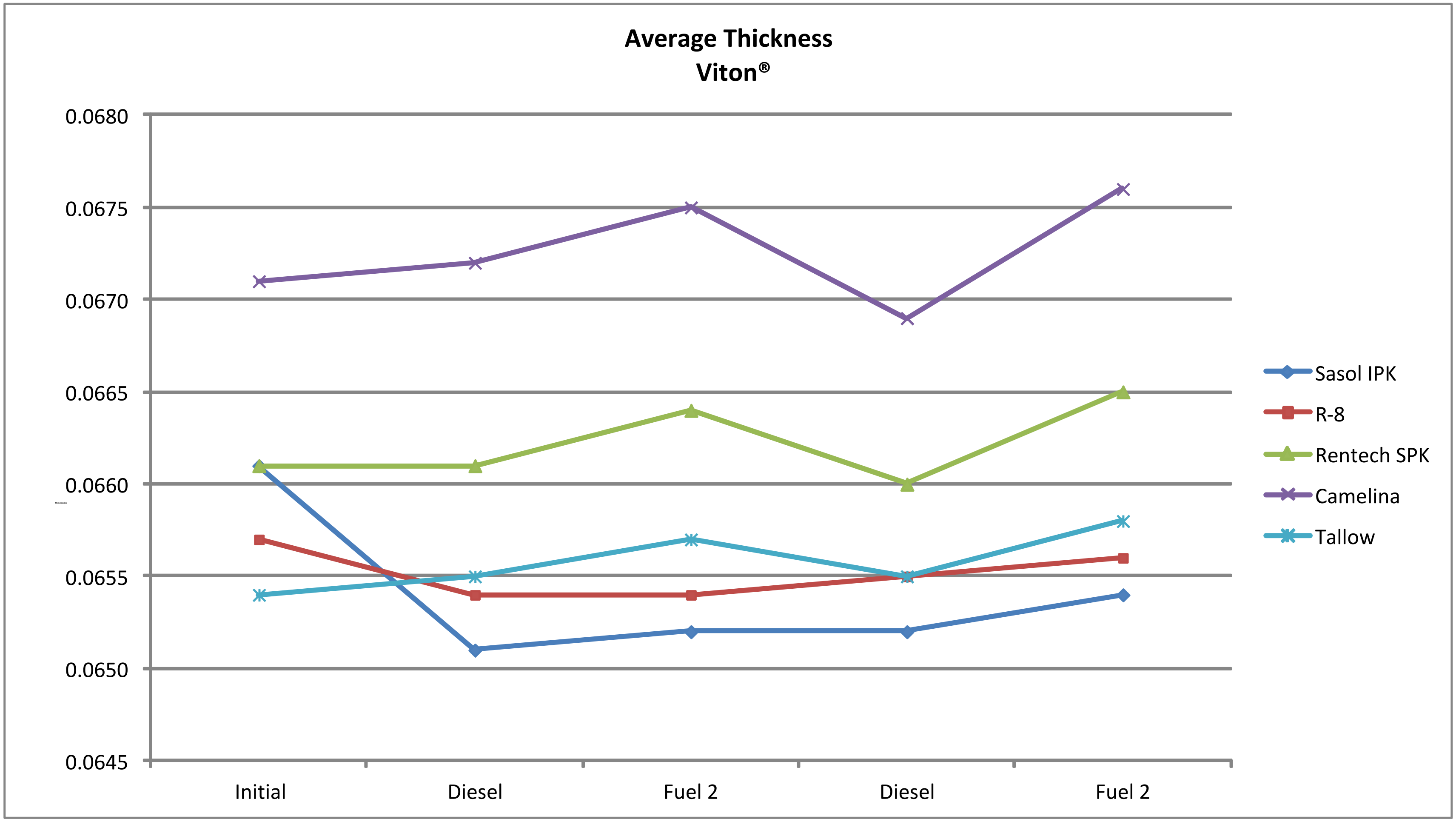

Figure 53. Thickness Data for Viton® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

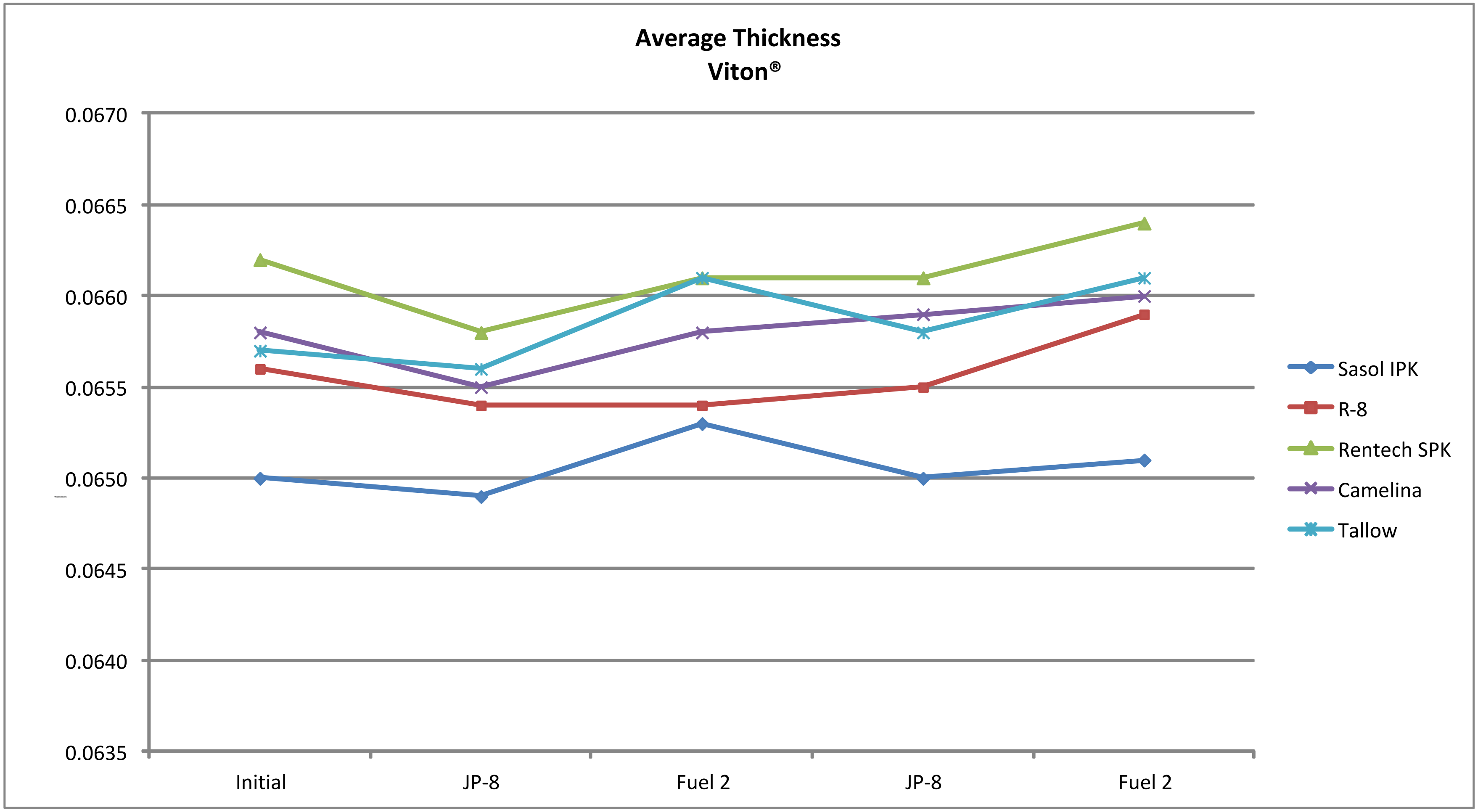

Figure 54. Thickness Data for Viton® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

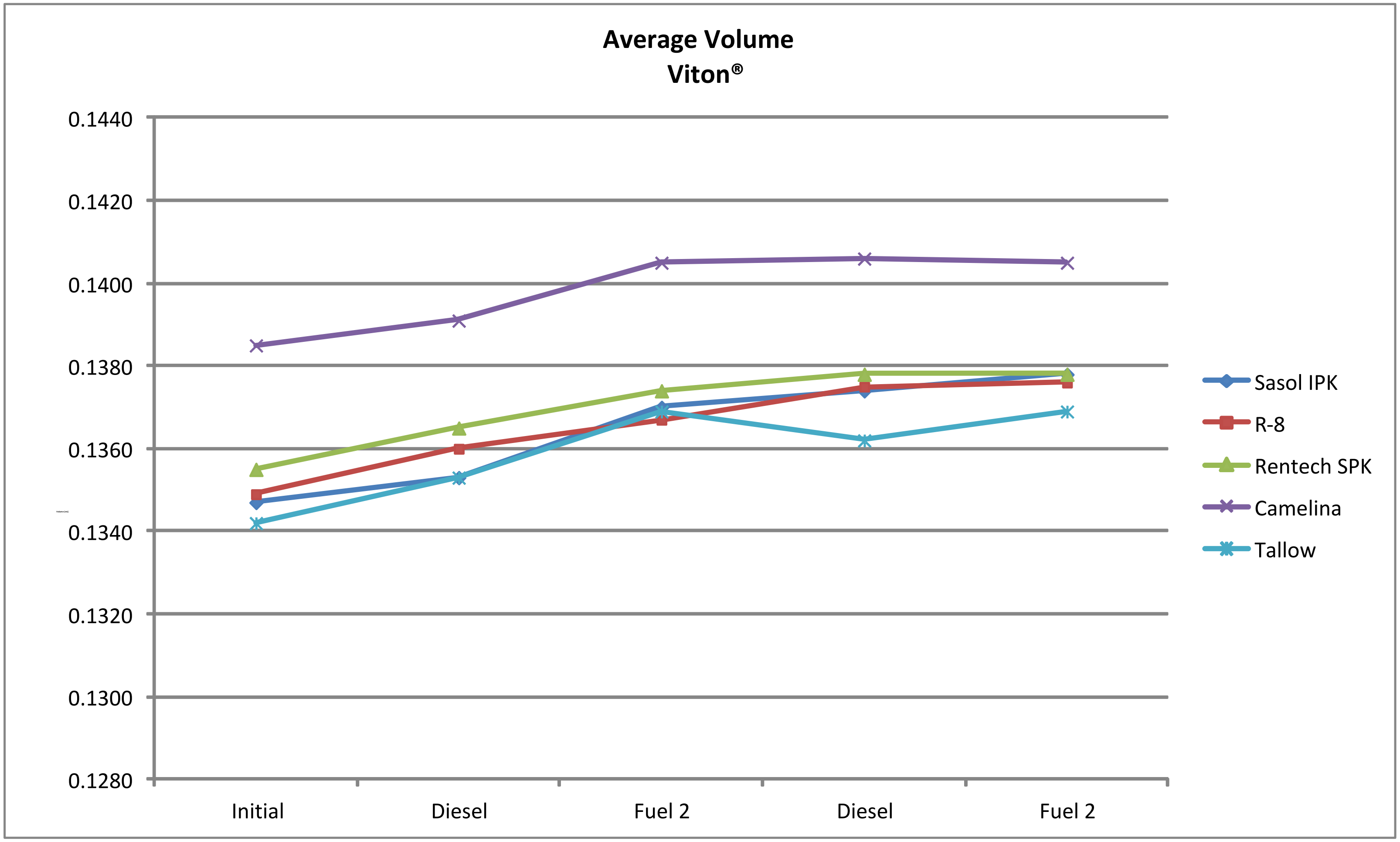

Figure 55. Volume Data for Viton® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

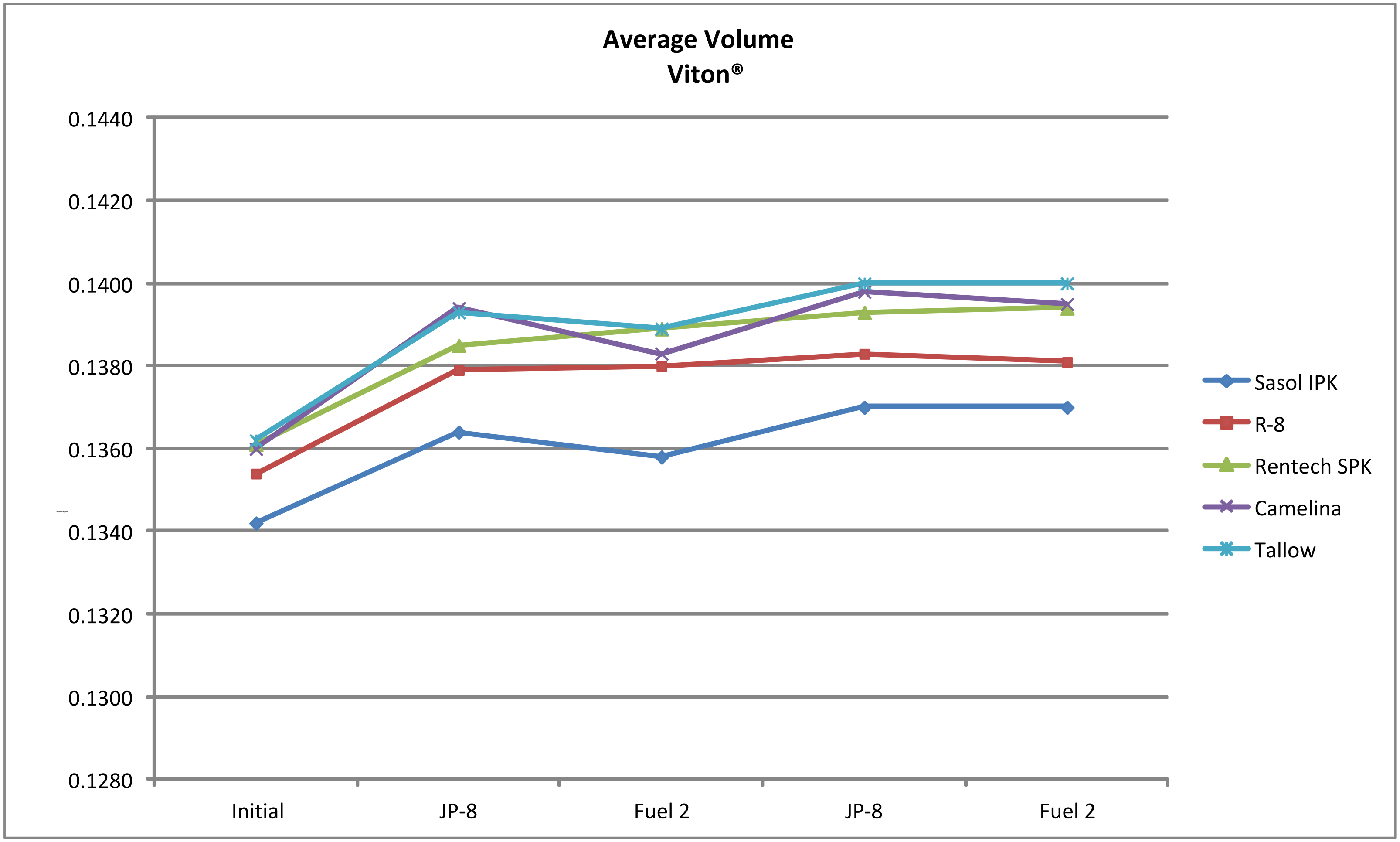

Figure 56. Volume Data for Viton® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

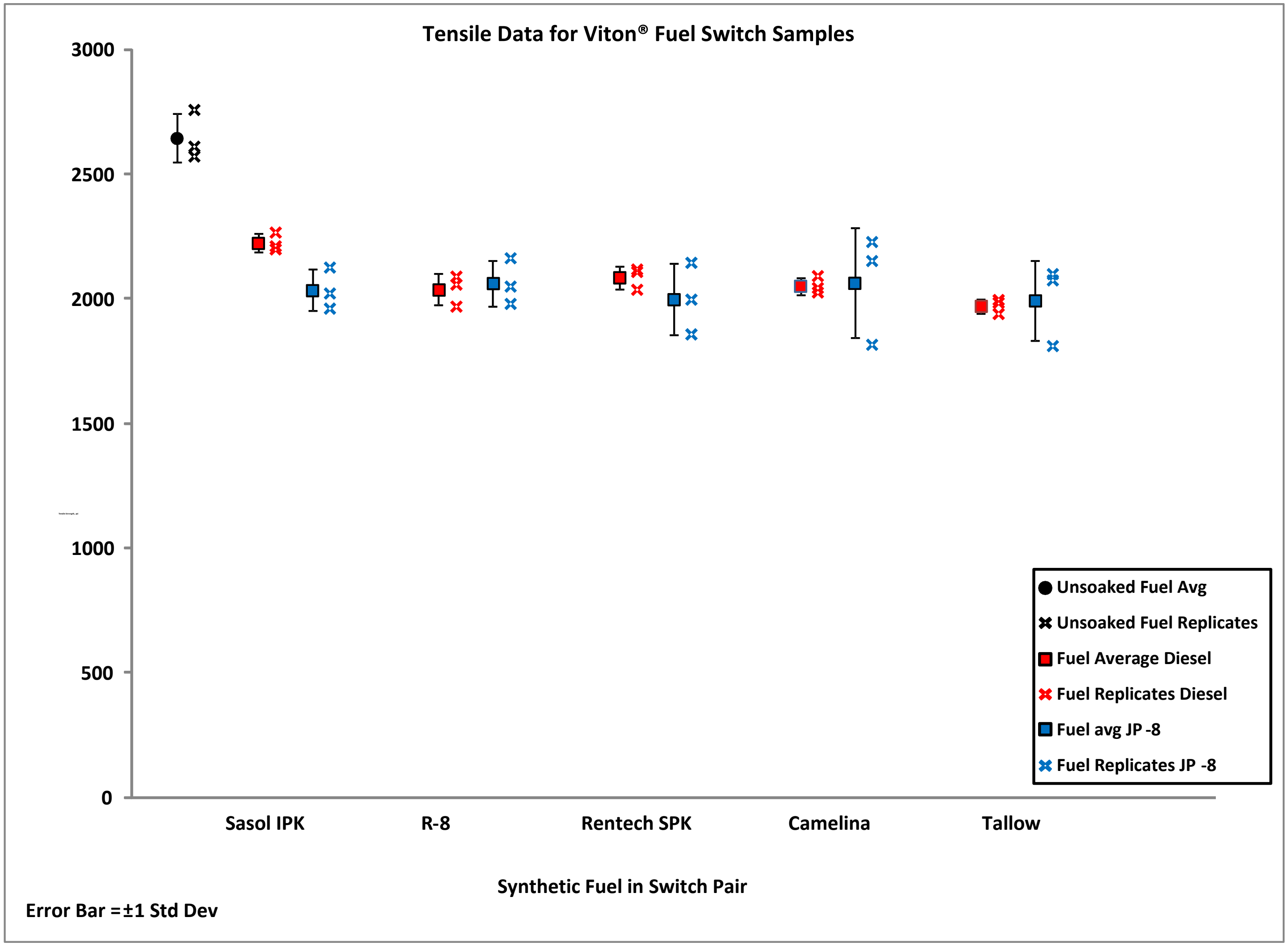

Figure 57. Tensile Strength Data for Viton® Switch-Loading Samples after 8 Weeks

3.2.5 Teflon® (Figure 58 to Figure 64)

An overall increase in hardness was observed. Thickness and volume remained fairly constant (e.g., 0.0005 in change in thickness and 0.0007 mL change in volume). The tensile strength data were consistent among the alternative fuel blends.

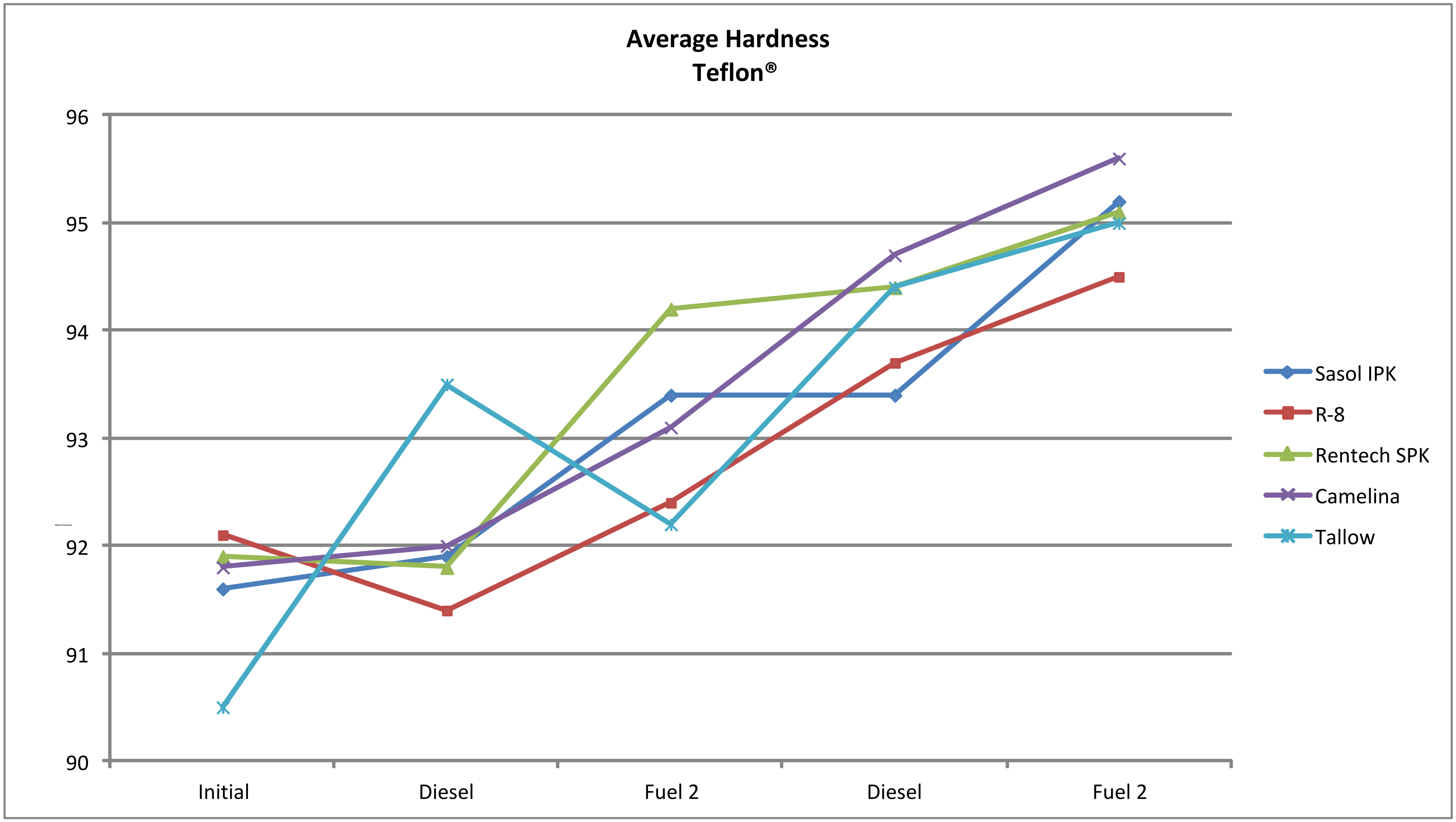

Figure 58. Hardness Data for Teflon® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

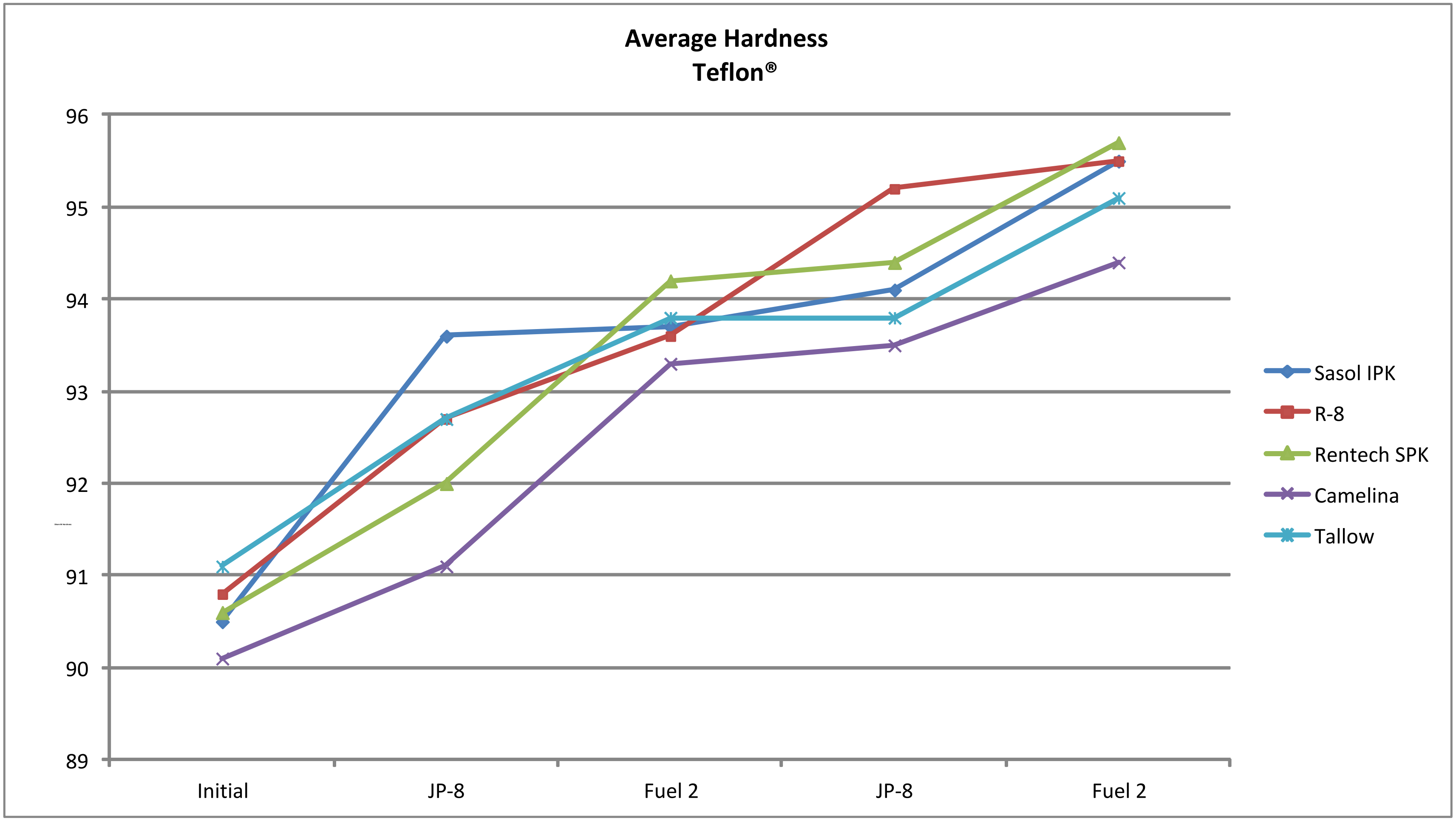

Figure 59. Hardness Data for Teflon® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

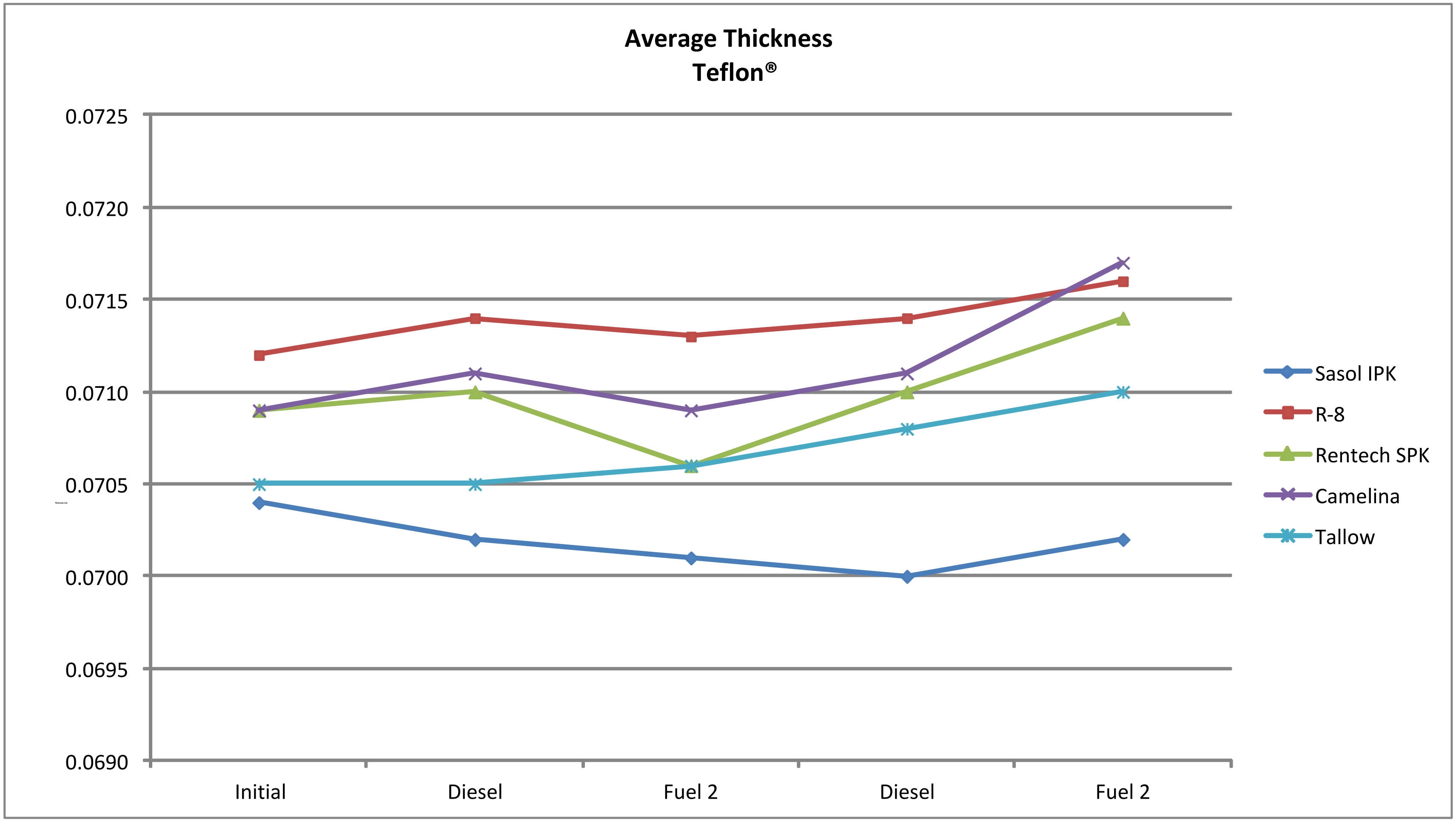

Figure 60. Thickness Data for Teflon® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

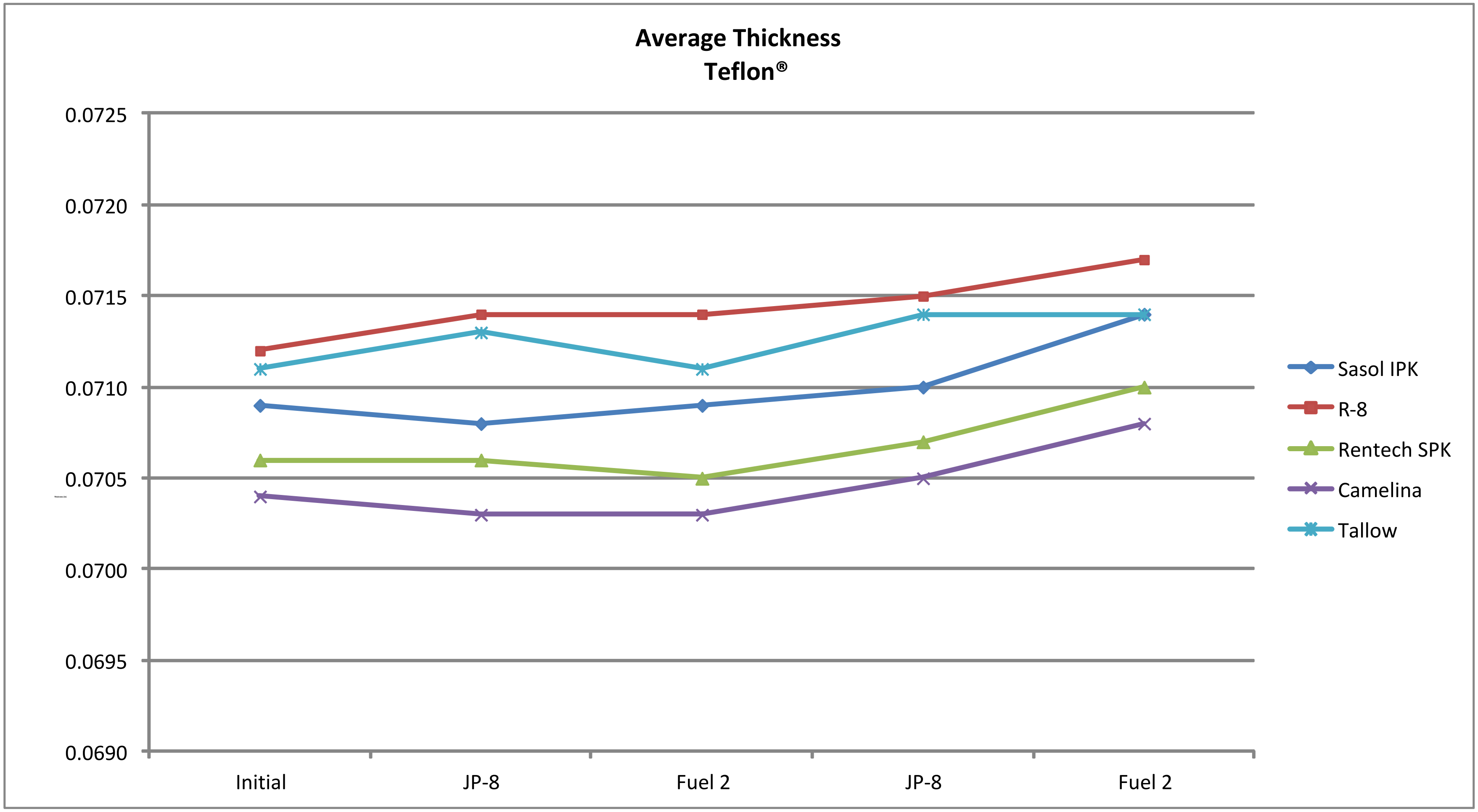

Figure 61. Thickness Data for Teflon® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

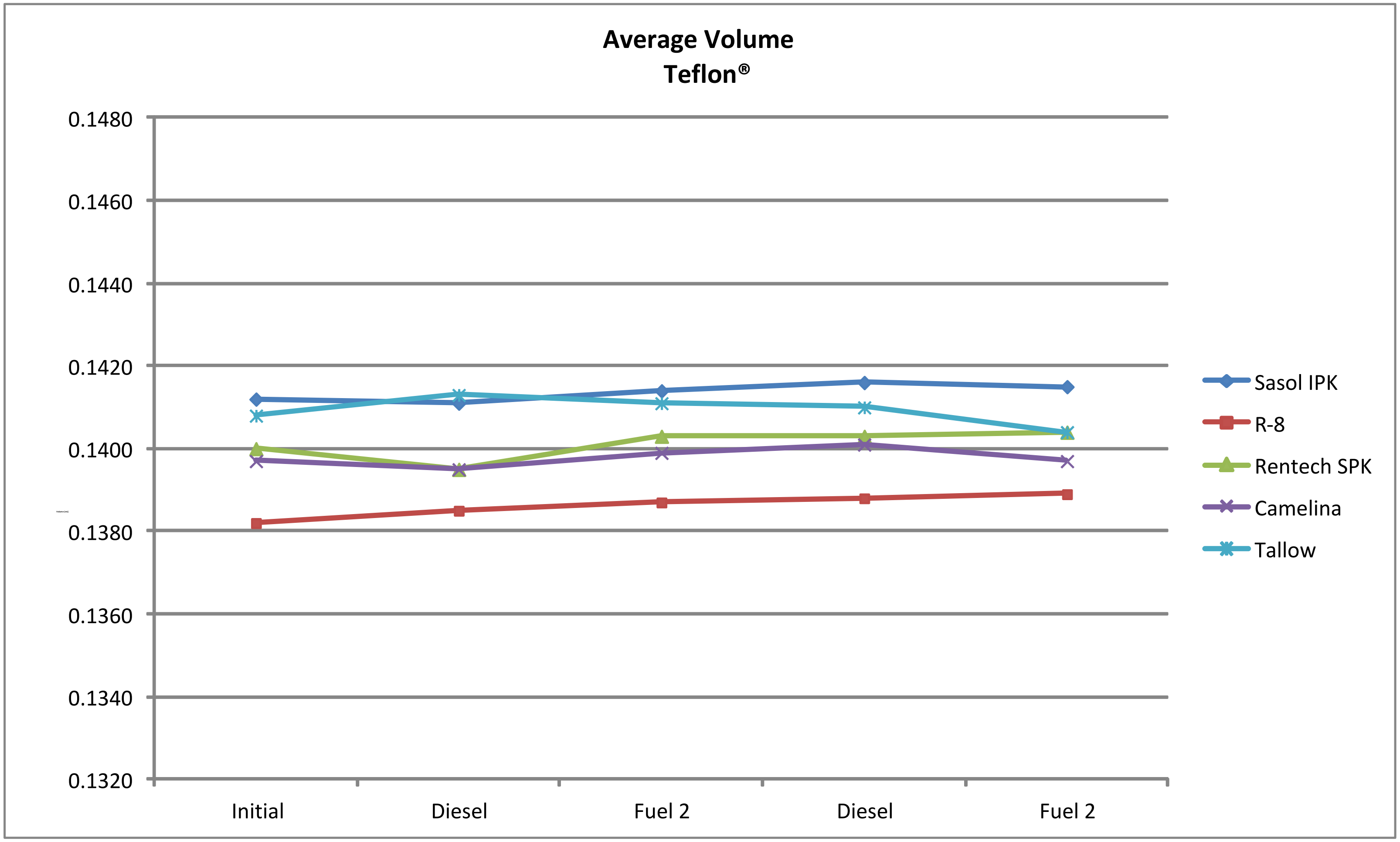

Figure 62. Volume Data for Teflon® Switch-Loading Samples after 8 Weeks with Diesel as the Baseline Fuel

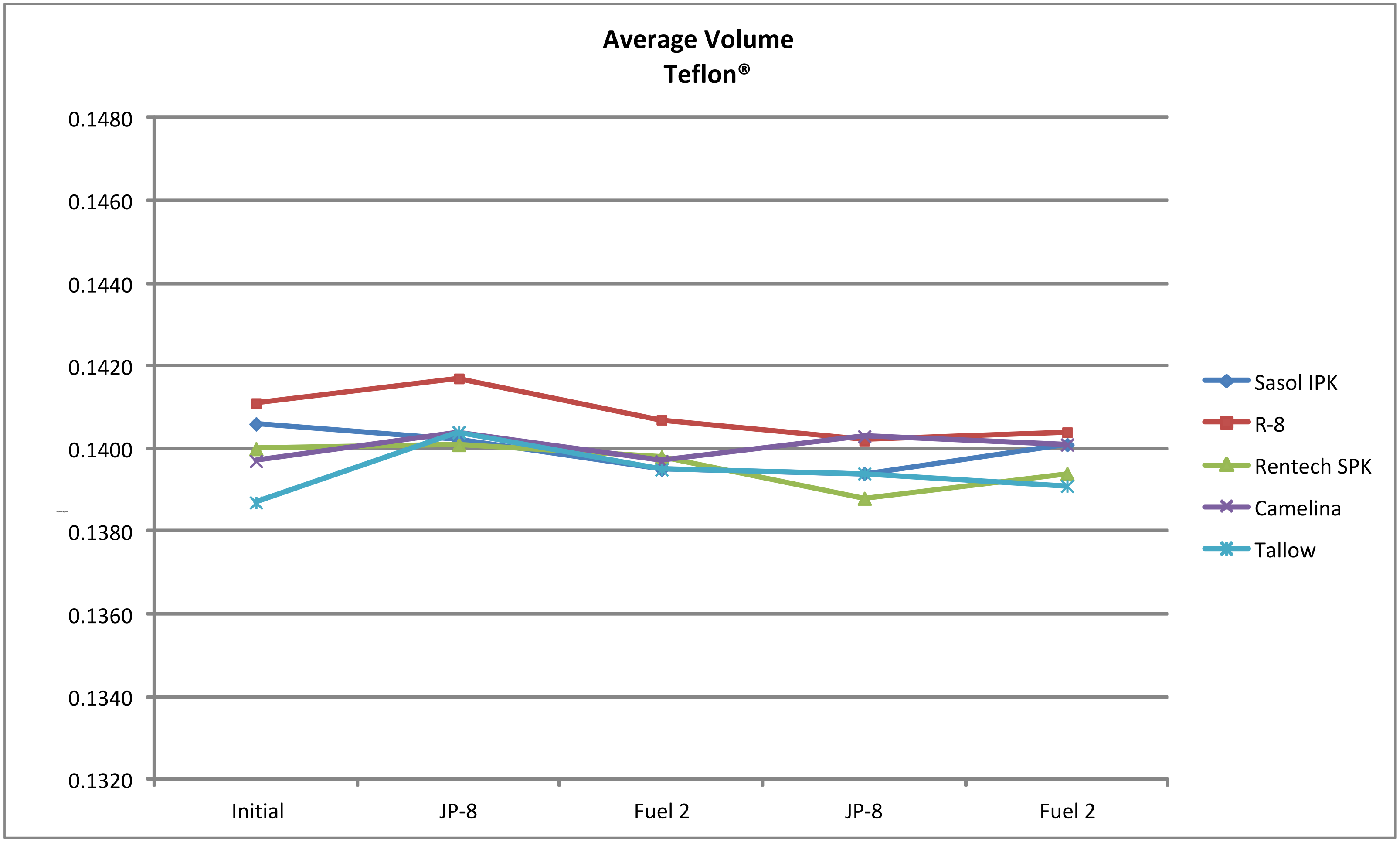

Figure 63. Volume Data for Teflon® Switch-Loading Samples after 8 Weeks with JP-8 as the Baseline Fuel

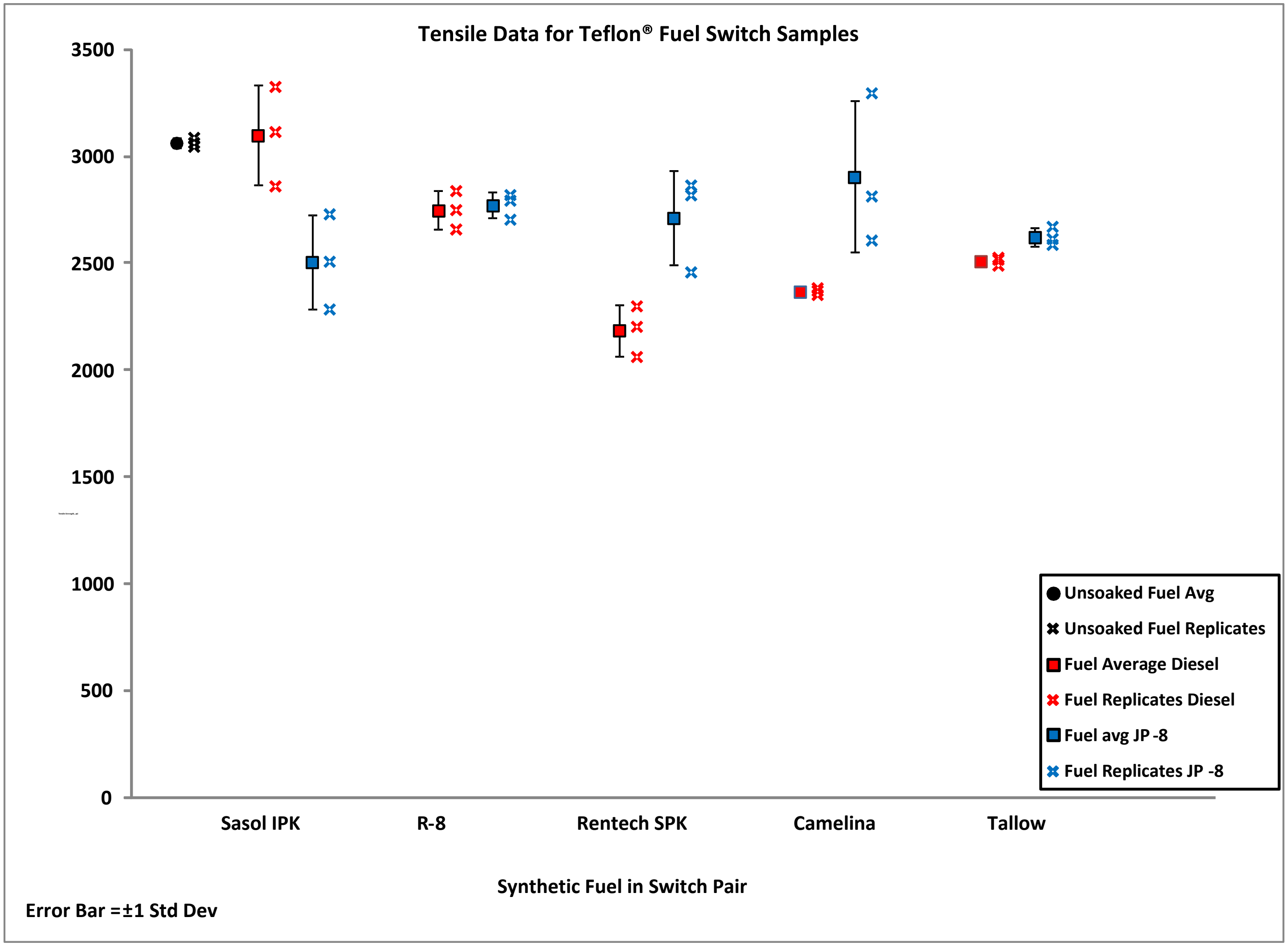

Figure 64. Tensile Strength Data for Teflon® Switch-Loading Samples after 8 Weeks

4.0 CONCLUSIONS

Polyurethane and fluorosilicone experienced the greatest property changes (e.g. reduced hardness, changes in thickness, reduced volume swell, increased compression set) resulting from exposure to the fuel. Teflon® was affected the least followed by Viton®, and then nitrile. When comparing the results between the 40 °C and 60 °C data, it appears that the temperature difference was not great enough to result in a large difference in the results.

The fuel switch loading data indicates that there were changes in thickness, hardness and volume swell when the samples were switched between fuels. The 50/50 alternative fuel blends generally followed the same trends as the baseline fuels. The same trend line was observed regardless of the baseline fuel, diesel or JP-8. The most significant trend was seen with hardness. A change in hardness resulting from extraction of compounds in the material could be considered an irreversible process. This was evidenced in the fuel switch study where the hardness of all of the materials continued to increase following each fuel switch regardless of the fuel. The fact that all fuels behaved this way is a positive note.

Overall, the results showed that there were some minor differences in property changes between the baseline fuels and the 50/50 alternative blends. In most cases, the effects on the material were very minimal and/or the effects were consistent across all fuels types. The differences observed do not appear sufficiently significant to cause any issues with the tactical fueling systems. Since the tolerances of the equipment is not known, it is still recommended that a chosen alternative fuel blend be tested with the hardware to ensure that proper seals are formed and leaks do not occur.

The aromatic content of the fuel has long been considered, and in some cases shown, to be a major factor in material compatibility. There's some empirical evidence suggesting that a minimum aromatic content of 8 vol% is necessary to ensure proper sealing of gaskets and O-rings. In this study, there were two primary factors that could have affected the results: aromatic content and fuel type. The petroleum-derived fuels generally have much higher aromatic contents (nominally 15% or higher). By selection of a 50/50 alternative fuel blend, this artificially set those fuel blends' aromatic content at approximately 10%. Fuel type is the other factor that may not have been given much consideration up to this point. The narrow composition of some of the alternative or synthetic fuels could alter their interaction with the material. In this study, several fuel types were used ranging from relatively high-aromatic, petroleum-derived ULSD and aviation fuel, to low aromatic IPK, SPK, and HEFA alternative fuel blends. Because of this limited matrix, it really doesn't allow for a definitive conclusion on the specific impact of aromatic content vs. fuel type but it's worth noting that a few of the results seem to suggest a different, albeit minimal, effect by certain fuel types.

Lastly, another factor to take into consideration is the quality of the alternative fuels. At the time this study was conducted, many of the alternative fuels available would have been considered experimental or first-run batches. Most of them had not been completely vetted through the normal qualification process. Although all of the fuels are hydrocarbon in nature, incomplete processing or remnants of unmodified basestock material could have a small impact on the results. Once the fuels are approved and shown to behave as drop-in replacements, the likelihood of a compatibility issue will drop significantly.

With regard to testing protocols, the methods used in this study are very common and used throughout industry for a variety of materials and fluids. The methods are flexible enough to allow variations in temperature and testing intervals and the results should form a good basis upon which to screen the likelihood of a problem. All of these methods are static in nature so the impact of motion or rubbing on the materials is not addressed in these tests. Under the right set of dynamic conditions, the minimal effects of the fuel could be increased many fold and lead to physical degradation of the material and early failure of the system. A dynamic seal tester, such as the one designed for TARDEC and in use at SwRI, could be used as another screening test beyond the normal static methods.

5.0 REFERENCES

1. Muzzell, P.; Stavinoha, L.; Sattler, E.; Terry, A.; Villahermosa, L. “Elastomer Impact When Switch-Loading Synthetic Fuel Blends and Petroleum Fuels”, TARDEC Report No. 16028, July 2006.

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6. ASTM International, ASTM D 1414 – 94, “Standard Test Method for Rubber O-Rings”, Approved May 1, 2008, Published June 2008.

7. ASTM International, ASTM D 395 – 03, “Standard Test Methods for Rubber Property – Compression Set”, Approved May 1, 2008, Published June 2008.

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APPENDIX A.

Jet A Certificate of Analysis

Alcor PetroLab, L.L.P.

20 Laboratory Road, Floresville, Texas 78114 Telephone 830-216-3113 www.alcorpetrolab.com

NuStar
San Antonio Products Terminal
P. O. Box 241017
San Antonio, Texas 78224-1017

February 22, 2010

Sample Type: Jet A
Tank Number.: 103
nt @ 1600 02/21/10 pu @ 0600 02/22/10

Sample Date: 02/22/10
Sample Time: 630

Volatility	Method	Specification		Result
Initial Boiling Point (^oF)	D 86			320.0
Distillation 10% Rec (^oF)		400	max	334.4
Distillation 50% Rec (^oF)		Report		365.9
Distillation 90% Rec (^oF)		Report		415.4
Distillation 95% Rec (^oF)		Report		433.4
Distillation Final BP (^oF)		572	max	459.5
Distillation Recovery (vol %)				98.9
Distillation Residue (vol %)		1.5	max	0.9
Distillation Loss (vol %)		1.5	max	0.2
Flash Point, Tag Closed (^oF)	D 56	100	min	121.0
API Gravity @ 60 (^oF)	D 1298	37.0 / 51.0		45.8
Cetane Index	D 4737	40.0	min	41.3
Particulate Matter Mgs/Gal	D 2276	3.0	max	0.8
Sulfur Wt %	D 7220	0.30	max	0.0001
Copper Strip	D130	No. 1	max	1A
Existent Gum Mgs / 100 Mls.	D381	7	max	<1.0
Fluidity				
Freezing Point (^oF)	D 2386	-41.0	max	-76.9
Contaminants				
Color (Saybolt)	D 156	+15	min	+30
Appearance	D4176	clear/bright	pass/fail	Pass
Water Reaction: Change	D 1094	2.0	max	0
Water Reaction: Interface Rating	D 1094	2	max	1
Water Reaction: Separation Rating	D 1094	2	max	1
MSEP	D 3948	85	min	99

This Product Conforms to ASTM D1655 for the Above Tests: XX YES ____ NO

Reviewed and submitted by,

Chris Taylor CEO

Report Number: P022210A

APPENDIX B.

Material Compatibility Tables

Table B-1. Hardness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Fluorosilicone	40	Camelina	-6.3
Fluorosilicone	60	Camelina	-8.6
Fluorosilicone	40	Diesel	-5.1
Fluorosilicone	60	Diesel	-3.6
Fluorosilicone	40	Jet A	-2.3
Fluorosilicone	60	Jet A	-2.4
Fluorosilicone	40	JP-8	-5.0
Fluorosilicone	60	JP-8	-5.4
Fluorosilicone	40	R-8	-6.3
Fluorosilicone	60	R-8	-5.0
Fluorosilicone	40	Rentech SPK	-4.5
Fluorosilicone	60	Rentech SPK	-5.2
Fluorosilicone	40	Sasol IPK	-2.8
Fluorosilicone	60	Sasol IPK	-3.3
Fluorosilicone	40	Tallow	-4.6
Fluorosilicone	60	Tallow	-3.5
Nitrile	40	Camelina	-1.4
Nitrile	60	Camelina	-2.1
Nitrile	40	Diesel	1.5
Nitrile	60	Diesel	0.6
Nitrile	40	Jet A	3.2
Nitrile	60	Jet A	3.0
Nitrile	40	JP-8	1.2
Nitrile	60	JP-8	1.0
Nitrile	40	R-8	1.6
Nitrile	60	R-8	0.5
Nitrile	40	Rentech SPK	-1.5
Nitrile	60	Rentech SPK	-0.8
Nitrile	40	Sasol IPK	1.7
Nitrile	60	Sasol IPK	3.9
Nitrile	40	Tallow	-0.7
Nitrile	60	Tallow	1.7
Polyurethane	40	Camelina	-6.9
Polyurethane	60	Camelina	-7.9
Polyurethane	40	Diesel	-5.3
Polyurethane	60	Diesel	-5.7

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Polyurethane	40	Jet A	-4.2

Table B-1 (Cont'd). Hardness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Polyurethane	60	Jet A	-4.3
Polyurethane	40	JP-8	-6.1
Polyurethane	60	JP-8	-5.2
Polyurethane	40	R-8	-8.3
Polyurethane	60	R-8	-11.4
Polyurethane	40	Rentech SPK	-5.9
Polyurethane	60	Rentech SPK	-9.6
Polyurethane	40	Sasol IPK	-5.8
Polyurethane	60	Sasol IPK	-5.7
Polyurethane	40	Tallow	-7.5
Polyurethane	60	Tallow	-8.6
Teflon®	40	Camelina	-3.5
Teflon®	60	Camelina	-0.4
Teflon®	40	Diesel	0.2
Teflon®	60	Diesel	0.4
Teflon®	40	Jet A	1.4
Teflon®	60	Jet A	2.3
Teflon®	40	JP-8	3.7
Teflon®	60	JP-8	2.0
Teflon®	40	R-8	3.1
Teflon®	60	R-8	1.9
Teflon®	40	Rentech SPK	1.0
Teflon®	60	Rentech SPK	1.4
Teflon®	40	Sasol IPK	2.6
Teflon®	60	Sasol IPK	2.6
Teflon®	40	Tallow	0.4
Teflon®	60	Tallow	2.8
Viton®	40	Camelina	-2.5
Viton®	60	Camelina	-2.1
Viton®	40	Diesel	0.5
Viton®	60	Diesel	0.6
Viton®	40	Jet A	1.8
Viton®	60	Jet A	0.9
Viton®	40	JP-8	-2.3

Table B-1 (Cont'd). Hardness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Viton®	60	JP-8	-0.6
Viton®	40	R-8	-0.6
Viton®	60	R-8	-0.3
Viton®	40	Rentech SPK	-0.8
Viton®	60	Rentech SPK	-0.3
Viton®	40	Sasol IPK	2.0
Viton®	60	Sasol IPK	2.4
Viton®	40	Tallow	-1.0
Viton®	60	Tallow	1.2

Table B-2. Thickness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Fluorosilicone	40	Camelina	0.6
Fluorosilicone	60	Camelina	1.6
Fluorosilicone	40	Diesel	-1.2
Fluorosilicone	60	Diesel	-1.9
Fluorosilicone	40	Jet A	-1.7
Fluorosilicone	60	Jet A	-1.6
Fluorosilicone	40	JP-8	-2.0
Fluorosilicone	60	JP-8	-1.2
Fluorosilicone	40	R-8	-1.8
Fluorosilicone	60	R-8	-1.7
Fluorosilicone	40	Rentech SPK	-1.8
Fluorosilicone	60	Rentech SPK	-0.1
Fluorosilicone	40	Sasol IPK	-2.5
Fluorosilicone	60	Sasol IPK	-2.2
Fluorosilicone	40	Tallow	-0.4
Fluorosilicone	60	Tallow	1.3
Nitrile	40	Camelina	1.6
Nitrile	60	Camelina	1.8
Nitrile	40	Diesel	2.1
Nitrile	60	Diesel	1.3
Nitrile	40	Jet A	0.5
Nitrile	60	Jet A	1.0
Nitrile	40	JP-8	0.9
Nitrile	60	JP-8	0.5
Nitrile	40	R-8	0.1
Nitrile	60	R-8	0.3
Nitrile	40	Rentech SPK	-0.2
Nitrile	60	Rentech SPK	1.1
Nitrile	40	Sasol IPK	0.4
Nitrile	60	Sasol IPK	0.8
Nitrile	40	Tallow	1.2
Nitrile	60	Tallow	1.1
Polyurethane	40	Camelina	5.2
Polyurethane	60	Camelina	5.3
Polyurethane	40	Diesel	5.8
Polyurethane	60	Diesel	6.3
Polyurethane	40	Jet A	6.5

Table B-2 (Cont'd). Thickness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Polyurethane	60	Jet A	6.6
Polyurethane	40	JP-8	6.9
Polyurethane	60	JP-8	7.8
Polyurethane	40	R-8	3.2
Polyurethane	60	R-8	2.7
Polyurethane	40	Rentech SPK	3.6
Polyurethane	60	Rentech SPK	4.2
Polyurethane	40	Sasol IPK	3.7
Polyurethane	60	Sasol IPK	4.5
Polyurethane	40	Tallow	4.4
Polyurethane	60	Tallow	4.1
Teflon®	40	Camelina	0.7
Teflon®	60	Camelina	0.5
Teflon®	40	Diesel	-0.1
Teflon®	60	Diesel	-0.1
Teflon®	40	Jet A	0.5
Teflon®	60	Jet A	0.2
Teflon®	40	JP-8	-0.2
Teflon®	60	JP-8	-0.3
Teflon®	40	R-8	0.0
Teflon®	60	R-8	0.0
Teflon®	40	Rentech SPK	0.1
Teflon®	60	Rentech SPK	0.1
Teflon®	40	Sasol IPK	-0.2
Teflon®	60	Sasol IPK	-0.8
Teflon®	40	Tallow	0.1
Teflon®	60	Tallow	-0.2
Viton®	40	Camelina	0.5
Viton®	60	Camelina	1.2
Viton®	40	Diesel	-0.2
Viton®	60	Diesel	0.2
Viton®	40	Jet A	-0.2
Viton®	60	Jet A	0.0
Viton®	40	JP-8	-0.1
Viton®	60	JP-8	0.5
Viton®	40	R-8	-0.8
Viton®	60	R-8	-0.7

Table B-2 (Cont'd). Thickness Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Viton®	40	Rentech SPK	-0.9
Viton®	60	Rentech SPK	0.1
Viton®	40	Sasol IPK	0.3
Viton®	60	Sasol IPK	0.1
Viton®	40	Tallow	0.2
Viton®	60	Tallow	0.2

Table B-3. Volume Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Fluorosilicone	40	Camelina	9.2
Fluorosilicone	60	Camelina	9.0
Fluorosilicone	40	Diesel	5.7
Fluorosilicone	60	Diesel	5.2
Fluorosilicone	40	Jet A	6.3
Fluorosilicone	60	Jet A	7.8
Fluorosilicone	40	JP-8	7.8
Fluorosilicone	60	JP-8	8.4
Fluorosilicone	40	R-8	7.5
Fluorosilicone	60	R-8	8.1
Fluorosilicone	40	Rentech SPK	7.9
Fluorosilicone	60	Rentech SPK	8.1
Fluorosilicone	40	Sasol IPK	8.7
Fluorosilicone	60	Sasol IPK	8.5
Fluorosilicone	40	Tallow	7.2
Fluorosilicone	60	Tallow	8.4
Nitrile	40	Camelina	9.3
Nitrile	60	Camelina	7.8
Nitrile	40	Diesel	10.8
Nitrile	60	Diesel	9.9
Nitrile	40	Jet A	10.3
Nitrile	60	Jet A	9.1
Nitrile	40	JP-8	10.7
Nitrile	60	JP-8	8.5
Nitrile	40	R-8	7.8
Nitrile	60	R-8	6.4
Nitrile	40	Rentech SPK	8.2
Nitrile	60	Rentech SPK	6.2
Nitrile	40	Sasol IPK	8.2
Nitrile	60	Sasol IPK	7.8
Nitrile	40	Tallow	8.0
Nitrile	60	Tallow	6.7
Polyurethane	40	Camelina	30.9
Polyurethane	60	Camelina	32.9
Polyurethane	40	Diesel	37.6
Polyurethane	60	Diesel	40.9
Polyurethane	40	Jet A	38.7

Table B-3 (Cont'd). Volume Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Polyurethane	60	Jet A	42.4
Polyurethane	40	JP-8	40.1
Polyurethane	60	JP-8	44.6
Polyurethane	40	R-8	27.9
Polyurethane	60	R-8	32.9
Polyurethane	40	Rentech SPK	28.3
Polyurethane	60	Rentech SPK	31.9
Polyurethane	40	Sasol IPK	29.9
Polyurethane	60	Sasol IPK	33.9
Polyurethane	40	Tallow	28.7
Polyurethane	60	Tallow	32.0
Teflon®	40	Camelina	-0.7
Teflon®	60	Camelina	-0.5
Teflon®	40	Diesel	-0.3
Teflon®	60	Diesel	-0.1
Teflon®	40	Jet A	-0.5
Teflon®	60	Jet A	-0.6
Teflon®	40	JP-8	-1.6
Teflon®	60	JP-8	-0.5
Teflon®	40	R-8	-0.7
Teflon®	60	R-8	0.1
Teflon®	40	Rentech SPK	-1.0
Teflon®	60	Rentech SPK	-1.2
Teflon®	40	Sasol IPK	-1.8
Teflon®	60	Sasol IPK	-0.2
Teflon®	40	Tallow	-0.5
Teflon®	60	Tallow	0.2
Viton®	40	Camelina	2.2
Viton®	60	Camelina	2.2
Viton®	40	Diesel	1.1
Viton®	60	Diesel	2.1
Viton®	40	Jet A	0.4
Viton®	60	Jet A	2.1
Viton®	40	JP-8	1.8
Viton®	60	JP-8	2.2
Viton®	40	R-8	-0.7
Viton®	60	R-8	2.4
Viton®	40	Rentech SPK	1.1
Viton®	60	Rentech SPK	0.5

Table B-3 (Cont'd). Volume Data for Static Soak Samples

O-ring	Temperature (°C)	Fuel	Overall Average Change (%)
Viton®	40	Sasol IPK	2
Viton®	60	Sasol IPK	3
Viton®	40	Tallow	1.5
Viton®	60	Tallow	2.6

Table B-4. Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
Fluorosilicone	Diesel	40	907	758
			536	
			832	
Nitrile	Diesel	40	2113	2281
			2250	
			2479	
Viton®	Diesel	40	2373	2375
			2316	
			2437	
Polyurethane	Diesel	40	1033	1222
			1344	
			1289	
Teflon®	Diesel	40	2194	2597
			3304	
			2294	
Fluorosilicone	Diesel	60	752	881
			979	
			910	
Nitrile	Diesel	60	2584	2504
			2374	
			2553	
Viton®	Diesel	60	2149	2259
			2282	
			2347	
Polyurethane	Diesel	60	961	992
			958	
			1057	
Teflon®	Diesel	60	2296	2469
			2719	
			2391	
Fluorosilicone	JP-8	40	784	749
			697	
			767	
Nitrile	JP-8	40	1821	2091
			2129	
			2324	
Viton®	JP-8	40	2108	2110
			2214	
			2009	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
Polyurethane	JP-8	40	992	1055
			1132	
			1041	
Teflon®	JP-8	40	2638	2666
			2622	
			2738	
Fluorosilicone	JP-8	60	701	695
			724	
			660	
Nitrile	JP-8	60	2261	2010
			432	
			1759	
Viton®	JP-8	60	1995	2042
			1957	
			2173	
Polyurethane	JP-8	60	865	962
			923	
			1097	
Teflon®	JP-8	60	2791	2763
			2793	
			2706	
Fluorosilicone	Jet A	40	856	728
			538	
			790	
Nitrile	Jet A	40	1298	1904
			2068	
			2345	
Viton®	Jet A	40	2427	2350
			2213	
			2410	
Polyurethane	Jet A	40	1151	1023
			976	
			941	
Teflon®	Jet A	40	2688	2969
			3298	
			2922	
Fluorosilicone	Jet A	60	764	826
			874	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
			841	
Nitrile	Jet A	60	2133	2198
			2261	
			2202	
Viton®	Jet A	60	2378	2241
			2088	
			2258	
Polyurethane	Jet A	60	954	871
			668	
			991	
Teflon®	Jet A	60	2562	2396
			2375	
			2250	
Fluorosilicone	Sasol IPK	40	698	749
			830	
			718	
Nitrile	Sasol IPK	40	2022	1789
			1280	
			2067	
Viton®	Sasol IPK	40	2143	2066
			1970	
			2084	
Polyurethane	Sasol IPK	40	1244	1427
			1746	
			1293	
Teflon®	Sasol IPK	40	2363	2318
			2685	
			1906	
Fluorosilicone	Sasol IPK	60	722	799
			829	
			845	
Nitrile	Sasol IPK	60	1097	2014
			2608	
			2337	
Viton®	Sasol IPK	60	2263	2190
			2242	
			2065	
Polyurethane	Sasol IPK	60	1257	1353
			1389	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
			1411	
Teflon®	Sasol IPK	60	2900	2797
			2613	
			2877	
Fluorosilicone	R-8	40	874	799
			779	
			744	
Nitrile	R-8	40	2121	2267
			2299	
			2381	
Viton®	R-8	40	2068	2114
			2148	
			2126	
Polyurethane	R-8	40	1517	1212
			793	
			1327	
Teflon®	R-8	40	2569	2596
			2482	
			2737	
Fluorosilicone	R-8	60	721	734
			746	
			735	
Nitrile	R-8	60	2051	2068
			1550	
			2605	
Viton®	R-8	60	2040	2074
			2138	
			2044	
Polyurethane	R-8	60	1717	1410
			1421	
			1091	
Teflon®	R-8	60	2423	2416
			2325	
			2499	
Fluorosilicone	Rentech SPK	40	764	753
			731	
			762	
Nitrile	Rentech SPK	40	1698	1995
			2312	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
			1976	
Viton®	Rentech SPK	40	2005	2036
			2041	
			2062	
Polyurethane	Rentech SPK	40	1280	1364
			1463	
			1350	
Teflon®	Rentech SPK	40	3294	2845
			2478	
			2762	
Fluorosilicone	Rentech SPK	60	708	687
			735	
			619	
Nitrile	Rentech SPK	60	2093	2279
			2386	
			2359	
Viton®	Rentech SPK	60	2126	1795
			1522	
			1737	
Polyurethane	Rentech SPK	60	1462	1352
			1198	
			1397	
Teflon®	Rentech SPK	60	2524	2729
			2486	
			3178	
Fluorosilicone	Camelina	40	656	726
			775	
			749	
Nitrile	Camelina	40	1437	1846
			2182	
			1920	
Viton®	Camelina	40	2131	2114
			2023	
			2188	
Polyurethane	Camelina	40	1291	1143
			991	
			1147	
Teflon®	Camelina	40	2449	2417
			2488	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
			2315	
Fluorosilicone	Camelina	60	804	740
			725	
			690	
Nitrile	Camelina	60	2159	2180
			2191	
			2192	
Viton®	Camelina	60	2190	2071
			2081	
			1942	
Polyurethane	Camelina	60	1172	1186
			1221	
			1166	
Teflon®	Camelina	60	2549	2743
			3272	
			2409	
Fluorosilicone	Tallow	40	737	752
			791	
			728	
Nitrile	Tallow	40	2403	2037
			2282	
			1425	
Viton®	Tallow	40	1959	2123
			2250	
			2160	
Polyurethane	Tallow	40	1622	1507
			1556	
			1342	
Teflon®	Tallow	40	2375	2467
			2474	
			2550	
Fluorosilicone	Tallow	60	583	683
			700	
			766	
Nitrile	Tallow	60	2321	2344
			2490	
			2222	
Viton®	Tallow	60	2021	1972
			1928	

Table B-4 (Cont'd). Tensile Strength Data for Static Soak Samples

Material	Fuel	Temperature (°C)	Tensile Strength (psi)	Avg Tensile Strength (psi)
			1969	
Polyurethane	Tallow	60	1217	1257
			1155	
			1399	
Teflon®	Tallow	60	3269	2989
			3302	
			2396	

Table B-5. Compression Set Data for Static Soak Samples

Material	Fuel	% Compression Set
Fluorosilicone	Air	26
Fluorosilicone	Diesel	30
Fluorosilicone	JP-8	35
Fluorosilicone	Jet A	25
Fluorosilicone	Sasol IPK	37
Fluorosilicone	R-8	27
Fluorosilicone	Rentech SPK	31
Fluorosilicone	Camelina	29
Fluorosilicone	Tallow	21
Nitrile	Air	6
Nitrile	Diesel	11
Nitrile	JP-8	3
Nitrile	Jet A	4
Nitrile	Sasol IPK	2
Nitrile	R-8	6
Nitrile	Rentech SPK	4
Nitrile	Camelina	2
Nitrile	Tallow	9
Viton	Air	6
Viton	Diesel	18
Viton	JP-8	15
Viton	Jet A	14
Viton	Sasol IPK	17
Viton	R-8	14
Viton	Rentech SPK	22
Viton	Camelina	15
Viton	Tallow	24
Polyurethane	Air	5
Polyurethane	Diesel	12
Polyurethane	JP-8	6
Polyurethane	Jet A	2
Polyurethane	Sasol IPK	12
Polyurethane	R-8	6
Polyurethane	Rentech SPK	11
Polyurethane	Camelina	12
Polyurethane	Tallow	13

Table B-6. Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Fluorosilicone	0	Initial	68.7
Fluorosilicone	1-2	Diesel	66.1
Fluorosilicone	3-4	Sasol IPK	65.1
Fluorosilicone	5-6	Diesel	66.6
Fluorosilicone	7-8	Sasol IPK	66.8
Nitrile	0	Initial	64.9
Nitrile	1-2	Diesel	64.4
Nitrile	3-4	Sasol IPK	64.9
Nitrile	5-6	Diesel	66.1
Nitrile	7-8	Sasol IPK	67.3
Viton®	0	Initial	68.7
Viton®	1-2	Diesel	67.5
Viton®	3-4	Sasol IPK	68.5
Viton®	5-6	Diesel	70.3
Viton®	7-8	Sasol IPK	70.5
Polyurethane	0	Initial	69.0
Polyurethane	1-2	Diesel	65.3
Polyurethane	3-4	Sasol IPK	65.2
Polyurethane	5-6	Diesel	65.4
Polyurethane	7-8	Sasol IPK	66.8
Teflon®	0	Initial	91.6
Teflon®	1-2	Diesel	91.9
Teflon®	3-4	Sasol IPK	93.4
Teflon®	5-6	Diesel	93.4
Teflon®	7-8	Sasol IPK	95.2
Fluorosilicone	0	Initial	68.1
Fluorosilicone	1-2	Diesel	65.4
Fluorosilicone	3-4	R-8	64.9
Fluorosilicone	5-6	Diesel	66.9
Fluorosilicone	7-8	R-8	66.3
Nitrile	0	Initial	63.9
Nitrile	1-2	Diesel	64.0
Nitrile	3-4	R-8	64.9
Nitrile	5-6	Diesel	65.8
Nitrile	7-8	R-8	66.8

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Viton®	0	Initial	69.2
Viton®	1-2	Diesel	69.7
Viton®	3-4	R-8	70.5
Viton®	5-6	Diesel	71.6
Viton®	7-8	R-8	72.3
Polyurethane	0	Initial	67.7
Polyurethane	1-2	Diesel	64.7
Polyurethane	3-4	R-8	65.3
Polyurethane	5-6	Diesel	64.3
Polyurethane	7-8	R-8	65.2
Teflon®	0	Initial	92.1
Teflon®	1-2	Diesel	91.4
Teflon®	3-4	R-8	92.4
Teflon®	5-6	Diesel	93.7
Teflon®	7-8	R-8	94.5
Fluorosilicone	0	Initial	68.6
Fluorosilicone	1-2	Diesel	66.4
Fluorosilicone	3-4	Rentech SPK	65.1
Fluorosilicone	5-6	Diesel	67.7
Fluorosilicone	7-8	Rentech SPK	66.8
Nitrile	0	Initial	64.9
Nitrile	1-2	Diesel	63.8
Nitrile	3-4	Rentech SPK	64.8
Nitrile	5-6	Diesel	65.7
Nitrile	7-8	Rentech SPK	66.5
Viton®	0	Initial	71.5
Viton®	1-2	Diesel	71.9
Viton®	3-4	Rentech SPK	70.4
Viton®	5-6	Diesel	73.6
Viton®	7-8	Rentech SPK	73.1
Polyurethane	0	Initial	67.9
Polyurethane	1-2	Diesel	64.7
Polyurethane	3-4	Rentech SPK	64.2
Polyurethane	5-6	Diesel	64.5

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Polyurethane	7-8	Rentech SPK	65.2
Teflon®	0	Initial	91.9
Teflon®	1-2	Diesel	91.8
Teflon®	3-4	Rentech SPK	94.2
Teflon®	5-6	Diesel	94.4
Teflon®	7-8	Rentech SPK	95.1
Fluorosilicone	0	Initial	68.4
Fluorosilicone	1-2	Diesel	66
Fluorosilicone	3-4	Camelina	65.4
Fluorosilicone	5-6	Diesel	66.9
Fluorosilicone	7-8	Camelina	66.7
Nitrile	0	Initial	63.6
Nitrile	1-2	Diesel	63.9
Nitrile	3-4	Camelina	65.2
Nitrile	5-6	Diesel	65.6
Nitrile	7-8	Camelina	66.2
Viton®	0	Initial	72.9
Viton®	1-2	Diesel	72.9
Viton®	3-4	Camelina	72.7
Viton®	5-6	Diesel	74.1
Viton®	7-8	Camelina	74.2
Polyurethane	0	Initial	68.8
Polyurethane	1-2	Diesel	65.0
Polyurethane	3-4	Camelina	65.3
Polyurethane	5-6	Diesel	65.5
Polyurethane	7-8	Camelina	66.2
Teflon®	0	Initial	91.8
Teflon®	1-2	Diesel	92.0
Teflon®	3-4	Camelina	93.1
Teflon®	5-6	Diesel	94.7
Teflon®	7-8	Camelina	95.6
Fluorosilicone	0	Initial	68.3
Fluorosilicone	1-2	Diesel	65.6
Fluorosilicone	3-4	Tallow	65

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Fluorosilicone	5-6	Diesel	66.6
Fluorosilicone	7-8	Tallow	66.6
Nitrile	0	Initial	64.7
Nitrile	1-2	Diesel	65.3
Nitrile	3-4	Tallow	65.7
Nitrile	5-6	Diesel	66.2
Nitrile	7-8	Tallow	67.4
Viton®	0	Initial	68.7
Viton®	1-2	Diesel	69.1
Viton®	3-4	Tallow	69.2
Viton®	5-6	Diesel	70.9
Viton®	7-8	Tallow	72.1
Polyurethane	0	Initial	67.1
Polyurethane	1-2	Diesel	63.5
Polyurethane	3-4	Tallow	62.5
Polyurethane	5-6	Diesel	62.6
Polyurethane	7-8	Tallow	62.8
Teflon®	0	Initial	90.5
Teflon®	1-2	Diesel	93.5
Teflon®	3-4	Tallow	92.2
Teflon®	5-6	Diesel	94.4
Teflon®	7-8	Tallow	95.0
Fluorosilicone	0	Initial	69.5
Fluorosilicone	1-2	JP-8	64.5
Fluorosilicone	3-4	Sasol IPK	65.7
Fluorosilicone	5-6	JP-8	66.7
Fluorosilicone	7-8	Sasol IPK	67.3
Nitrile	0	Initial	63.6
Nitrile	1-2	JP-8	63.0
Nitrile	3-4	Sasol IPK	64.2
Nitrile	5-6	JP-8	64.4
Nitrile	7-8	Sasol IPK	65.8
Viton®	0	Initial	67.9
Viton®	1-2	JP-8	66.7

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Viton®	3-4	Sasol IPK	68.0
Viton®	5-6	JP-8	67.9
Viton®	7-8	Sasol IPK	70.1
Polyurethane	0	Initial	69.7
Polyurethane	1-2	JP-8	68.1
Polyurethane	3-4	Sasol IPK	65.6
Polyurethane	5-6	JP-8	65.2
Polyurethane	7-8	Sasol IPK	65.4
Teflon®	0	Initial	90.5
Teflon®	1-2	JP-8	93.6
Teflon®	3-4	Sasol IPK	93.7
Teflon®	5-6	JP-8	94.1
Teflon®	7-8	Sasol IPK	95.5
Fluorosilicone	0	Initial	70.6
Fluorosilicone	1-2	JP-8	65.9
Fluorosilicone	3-4	R-8	66.7
Fluorosilicone	5-6	JP-8	66.8
Fluorosilicone	7-8	R-8	67.3
Nitrile	0	Initial	64.5
Nitrile	1-2	JP-8	65.0
Nitrile	3-4	R-8	65.7
Nitrile	5-6	JP-8	65.9
Nitrile	7-8	R-8	66.7
Viton®	0	Initial	68.2
Viton®	1-2	JP-8	69.3
Viton®	3-4	R-8	69.9
Viton®	5-6	JP-8	70.2
Viton®	7-8	R-8	71.1
Polyurethane	0	Initial	68.1
Polyurethane	1-2	JP-8	66.0
Polyurethane	3-4	R-8	65.4
Polyurethane	5-6	JP-8	65.4
Polyurethane	7-8	R-8	65.9
Teflon®	0	Initial	90.8

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Teflon®	1-2	JP-8	92.7
Teflon®	3-4	R-8	93.6
Teflon®	5-6	JP-8	95.2
Teflon®	7-8	R-8	95.5
Fluorosilicone	0	Initial	68.1
Fluorosilicone	1-2	JP-8	64.3
Fluorosilicone	3-4	Rentech SPK	64.8
Fluorosilicone	5-6	JP-8	65.5
Fluorosilicone	7-8	Rentech SPK	66.7
Nitrile	0	Initial	64.3
Nitrile	1-2	JP-8	64.8
Nitrile	3-4	Rentech SPK	65.4
Nitrile	5-6	JP-8	66.4
Nitrile	7-8	Rentech SPK	67.1
Viton®	0	Initial	69.7
Viton®	1-2	JP-8	70.4
Viton®	3-4	Rentech SPK	71.4
Viton®	5-6	JP-8	71.7
Viton®	7-8	Rentech SPK	73.1
Polyurethane	0	Initial	66.7
Polyurethane	1-2	JP-8	65.1
Polyurethane	3-4	Rentech SPK	64.4
Polyurethane	5-6	JP-8	65.1
Polyurethane	7-8	Rentech SPK	64.7
Teflon®	0	Initial	90.6
Teflon®	1-2	JP-8	92.0
Teflon®	3-4	Rentech SPK	94.2
Teflon®	5-6	JP-8	94.4
Teflon®	7-8	Rentech SPK	95.7
Fluorosilicone	0	Initial	67.9
Fluorosilicone	1-2	JP-8	65.5
Fluorosilicone	3-4	Camelina	67.3
Fluorosilicone	5-6	JP-8	66.7
Fluorosilicone	7-8	Camelina	67.3

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Nitrile	0	Initial	64.3
Nitrile	1-2	JP-8	64.9
Nitrile	3-4	Camelina	65.6
Nitrile	5-6	JP-8	66.3
Nitrile	7-8	Camelina	66.7
Viton®	0	Initial	70.1
Viton®	1-2	JP-8	69.8
Viton®	3-4	Camelina	71.3
Viton®	5-6	JP-8	71.3
Viton®	7-8	Camelina	72.4
Polyurethane	0	Initial	67.7
Polyurethane	1-2	JP-8	65.1
Polyurethane	3-4	Camelina	64.5
Polyurethane	5-6	JP-8	65.3
Polyurethane	7-8	Camelina	65.6
Teflon®	0	Initial	90.1
Teflon®	1-2	JP-8	91.1
Teflon®	3-4	Camelina	93.3
Teflon®	5-6	JP-8	93.5
Teflon®	7-8	Camelina	94.4
Fluorosilicone	0	Initial	68.4
Fluorosilicone	1-2	JP-8	65.4
Fluorosilicone	3-4	Tallow	65.6
Fluorosilicone	5-6	JP-8	65.6
Fluorosilicone	7-8	Tallow	66.7
Nitrile	0	Initial	65.7
Nitrile	1-2	JP-8	65.7
Nitrile	3-4	Tallow	65.8
Nitrile	5-6	JP-8	66.7
Nitrile	7-8	Tallow	68.0
Viton®	0	Initial	69.7
Viton®	1-2	JP-8	69.3
Viton®	3-4	Tallow	70.7
Viton®	5-6	JP-8	70.3

Table B-6 (Cont'd). Hardness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. hardness
Viton®	7-8	Tallow	72.0
Polyurethane	0	Initial	68.4
Polyurethane	1-2	JP-8	66.0
Polyurethane	3-4	Tallow	65.4
Polyurethane	5-6	JP-8	65.0
Polyurethane	7-8	Tallow	65.9
Teflon®	0	Initial	91.1
Teflon®	1-2	JP-8	92.7
Teflon®	3-4	Tallow	93.8
Teflon®	5-6	JP-8	93.8
Teflon®	7-8	Tallow	95.1

Table B-7. Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Fluorosilicone	0	Initial	0.0671
Fluorosilicone	1-2	Diesel	0.0655
Fluorosilicone	3-4	Sasol IPK	0.0648
Fluorosilicone	5-6	Diesel	0.0651
Fluorosilicone	7-8	Sasol IPK	0.0653
Nitrile	0	Initial	0.0654
Nitrile	1-2	Diesel	0.0651
Nitrile	3-4	Sasol IPK	0.0647
Nitrile	5-6	Diesel	0.0648
Nitrile	7-8	Sasol IPK	0.0648
Viton®	0	Initial	0.0661
Viton®	1-2	Diesel	0.0651
Viton®	3-4	Sasol IPK	0.0652
Viton®	5-6	Diesel	0.0652
Viton®	7-8	Sasol IPK	0.0654
Polyurethane	0	Initial	0.0680
Polyurethane	1-2	Diesel	0.0712
Polyurethane	3-4	Sasol IPK	0.0695
Polyurethane	5-6	Diesel	0.0707
Polyurethane	7-8	Sasol IPK	0.0700
Teflon®	0	Initial	0.0704
Teflon®	1-2	Diesel	0.0702
Teflon®	3-4	Sasol IPK	0.0701
Teflon®	5-6	Diesel	0.0700
Teflon®	7-8	Sasol IPK	0.0702
Fluorosilicone	0	Initial	0.0662
Fluorosilicone	1-2	Diesel	0.0653
Fluorosilicone	3-4	R-8	0.0645
Fluorosilicone	5-6	Diesel	0.0646
Fluorosilicone	7-8	R-8	0.0648
Nitrile	0	Initial	0.0640
Nitrile	1-2	Diesel	0.0646
Nitrile	3-4	R-8	0.0642
Nitrile	5-6	Diesel	0.0646
Nitrile	7-8	R-8	0.0645

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Viton®	0	Initial	0.0657
Viton®	1-2	Diesel	0.0654
Viton®	3-4	R-8	0.0654
Viton®	5-6	Diesel	0.0655
Viton®	7-8	R-8	0.0656
Polyurethane	0	Initial	0.0666
Polyurethane	1-2	Diesel	0.0705
Polyurethane	3-4	R-8	0.0687
Polyurethane	5-6	Diesel	0.0701
Polyurethane	7-8	R-8	0.0689
Teflon®	0	Initial	0.0712
Teflon®	1-2	Diesel	0.0714
Teflon®	3-4	R-8	0.0713
Teflon®	5-6	Diesel	0.0714
Teflon®	7-8	R-8	0.0716
Fluorosilicone	0	Initial	0.0663
Fluorosilicone	1-2	Diesel	0.0655
Fluorosilicone	3-4	Rentech SPK	0.0662
Fluorosilicone	5-6	Diesel	0.0652
Fluorosilicone	7-8	Rentech SPK	0.0660
Nitrile	0	Initial	0.0638
Nitrile	1-2	Diesel	0.0649
Nitrile	3-4	Rentech SPK	0.0650
Nitrile	5-6	Diesel	0.0647
Nitrile	7-8	Rentech SPK	0.0652
Viton®	0	Initial	0.0661
Viton®	1-2	Diesel	0.0661
Viton®	3-4	Rentech SPK	0.0664
Viton®	5-6	Diesel	0.0660
Viton®	7-8	Rentech SPK	0.0665
Polyurethane	0	Initial	0.0669
Polyurethane	1-2	Diesel	0.0706
Polyurethane	3-4	Rentech SPK	0.0698
Polyurethane	5-6	Diesel	0.0701

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Polyurethane	7-8	Rentech SPK	0.0696
Teflon®	0	Initial	0.0709
Teflon®	1-2	Diesel	0.0710
Teflon®	3-4	Rentech SPK	0.0706
Teflon®	5-6	Diesel	0.0710
Teflon®	7-8	Rentech SPK	0.0714
Fluorosilicone	0	Initial	0.0663
Fluorosilicone	1-2	Diesel	0.0656
Fluorosilicone	3-4	Camelina	0.0658
Fluorosilicone	5-6	Diesel	0.0643
Fluorosilicone	7-8	Camelina	0.0659
Nitrile	0	Initial	0.0637
Nitrile	1-2	Diesel	0.0645
Nitrile	3-4	Camelina	0.0645
Nitrile	5-6	Diesel	0.0642
Nitrile	7-8	Camelina	0.0647
Viton®	0	Initial	0.0671
Viton®	1-2	Diesel	0.0672
Viton®	3-4	Camelina	0.0675
Viton®	5-6	Diesel	0.0669
Viton®	7-8	Camelina	0.0676
Polyurethane	0	Initial	0.0669
Polyurethane	1-2	Diesel	0.0713
Polyurethane	3-4	Camelina	0.0698
Polyurethane	5-6	Diesel	0.0707
Polyurethane	7-8	Camelina	0.0699
Teflon®	0	Initial	0.0709
Teflon®	1-2	Diesel	0.0711
Teflon®	3-4	Camelina	0.0709
Teflon®	5-6	Diesel	0.0711
Teflon®	7-8	Camelina	0.0717
Fluorosilicone	0	Initial	0.0664
Fluorosilicone	1-2	Diesel	0.0654
Fluorosilicone	3-4	Tallow	0.0661

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Fluorosilicone	5-6	Diesel	0.0653
Fluorosilicone	7-8	Tallow	0.0656
Nitrile	0	Initial	0.0649
Nitrile	1-2	Diesel	0.0656
Nitrile	3-4	Tallow	0.0655
Nitrile	5-6	Diesel	0.0653
Nitrile	7-8	Tallow	0.0653
Viton®	0	Initial	0.0654
Viton®	1-2	Diesel	0.0655
Viton®	3-4	Tallow	0.0657
Viton®	5-6	Diesel	0.0655
Viton®	7-8	Tallow	0.0658
Polyurethane	0	Initial	0.0664
Polyurethane	1-2	Diesel	0.0698
Polyurethane	3-4	Tallow	0.0688
Polyurethane	5-6	Diesel	0.0697
Polyurethane	7-8	Tallow	0.0689
Teflon®	0	Initial	0.0705
Teflon®	1-2	Diesel	0.0705
Teflon®	3-4	Tallow	0.0706
Teflon®	5-6	Diesel	0.0708
Teflon®	7-8	Tallow	0.0710
Fluorosilicone	0	Initial	0.0668
Fluorosilicone	1-2	JP-8	0.0658
Fluorosilicone	3-4	Sasol IPK	0.0667
Fluorosilicone	5-6	JP-8	0.0655
Fluorosilicone	7-8	Sasol IPK	0.0662
Nitrile	0	Initial	0.0634
Nitrile	1-2	JP-8	0.0646
Nitrile	3-4	Sasol IPK	0.0646
Nitrile	5-6	JP-8	0.0644
Nitrile	7-8	Sasol IPK	0.0642
Viton®	0	Initial	0.0650
Viton®	1-2	JP-8	0.0649

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Viton®	3-4	Sasol IPK	0.0653
Viton®	5-6	JP-8	0.0650
Viton®	7-8	Sasol IPK	0.0651
Polyurethane	0	Initial	0.0675
Polyurethane	1-2	JP-8	0.0717
Polyurethane	3-4	Sasol IPK	0.0703
Polyurethane	5-6	JP-8	0.0716
Polyurethane	7-8	Sasol IPK	0.0703
Teflon®	0	Initial	0.0709
Teflon®	1-2	JP-8	0.0708
Teflon®	3-4	Sasol IPK	0.0709
Teflon®	5-6	JP-8	0.0710
Teflon®	7-8	Sasol IPK	0.0714
Fluorosilicone	0	Initial	0.0666
Fluorosilicone	1-2	JP-8	0.0655
Fluorosilicone	3-4	R-8	0.0652
Fluorosilicone	5-6	JP-8	0.0655
Fluorosilicone	7-8	R-8	0.0656
Nitrile	0	Initial	0.0641
Nitrile	1-2	JP-8	0.0647
Nitrile	3-4	R-8	0.0641
Nitrile	5-6	JP-8	0.0646
Nitrile	7-8	R-8	0.0644
Viton®	0	Initial	0.0656
Viton®	1-2	JP-8	0.0654
Viton®	3-4	R-8	0.0654
Viton®	5-6	JP-8	0.0655
Viton®	7-8	R-8	0.0659
Polyurethane	0	Initial	0.0669
Polyurethane	1-2	JP-8	0.0710
Polyurethane	3-4	R-8	0.0684
Polyurethane	5-6	JP-8	0.0705
Polyurethane	7-8	R-8	0.0687
Teflon®	0	Initial	0.0712

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Teflon®	1-2	JP-8	0.0714
Teflon®	3-4	R-8	0.0714
Teflon®	5-6	JP-8	0.0715
Teflon®	7-8	R-8	0.0717
Fluorosilicone	0	Initial	0.0656
Fluorosilicone	1-2	JP-8	0.0650
Fluorosilicone	3-4	Rentech SPK	0.0640
Fluorosilicone	5-6	JP-8	0.0644
Fluorosilicone	7-8	Rentech SPK	0.0648
Nitrile	0	Initial	0.0642
Nitrile	1-2	JP-8	0.0649
Nitrile	3-4	Rentech SPK	0.0645
Nitrile	5-6	JP-8	0.0646
Nitrile	7-8	Rentech SPK	0.0646
Viton®	0	Initial	0.0662
Viton®	1-2	JP-8	0.0658
Viton®	3-4	Rentech SPK	0.0661
Viton®	5-6	JP-8	0.0661
Viton®	7-8	Rentech SPK	0.0664
Polyurethane	0	Initial	0.0665
Polyurethane	1-2	JP-8	0.0705
Polyurethane	3-4	Rentech SPK	0.0681
Polyurethane	5-6	JP-8	0.0701
Polyurethane	7-8	Rentech SPK	0.0686
Teflon®	0	Initial	0.0706
Teflon®	1-2	JP-8	0.0706
Teflon®	3-4	Rentech SPK	0.0705
Teflon®	5-6	JP-8	0.0707
Teflon®	7-8	Rentech SPK	0.0710
Fluorosilicone	0	Initial	0.0664
Fluorosilicone	1-2	JP-8	0.0653
Fluorosilicone	3-4	Camelina	0.0651
Fluorosilicone	5-6	JP-8	0.0649
Fluorosilicone	7-8	Camelina	0.0654

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Nitrile	0	Initial	0.0639
Nitrile	1-2	JP-8	0.0648
Nitrile	3-4	Camelina	0.0640
Nitrile	5-6	JP-8	0.0646
Nitrile	7-8	Camelina	0.0644
Viton®	0	Initial	0.0658
Viton®	1-2	JP-8	0.0655
Viton®	3-4	Camelina	0.0658
Viton®	5-6	JP-8	0.0659
Viton®	7-8	Camelina	0.0660
Polyurethane	0	Initial	0.0668
Polyurethane	1-2	JP-8	0.0708
Polyurethane	3-4	Camelina	0.0685
Polyurethane	5-6	JP-8	0.0706
Polyurethane	7-8	Camelina	0.0689
Teflon®	0	Initial	0.0704
Teflon®	1-2	JP-8	0.0703
Teflon®	3-4	Camelina	0.0703
Teflon®	5-6	JP-8	0.0705
Teflon®	7-8	Camelina	0.0708
Fluorosilicone	0	Initial	0.0657
Fluorosilicone	1-2	JP-8	0.0647
Fluorosilicone	3-4	Tallow	0.0645
Fluorosilicone	5-6	JP-8	0.0644
Fluorosilicone	7-8	Tallow	0.0649
Nitrile	0	Initial	0.0645
Nitrile	1-2	JP-8	0.0654
Nitrile	3-4	Tallow	0.0649
Nitrile	5-6	JP-8	0.0653
Nitrile	7-8	Tallow	0.0648
Viton®	0	Initial	0.0657
Viton®	1-2	JP-8	0.0656
Viton®	3-4	Tallow	0.0661
Viton®	5-6	JP-8	0.0658

Table B-7 (Cont'd). Thickness Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Thickness (in)
Viton®	7-8	Tallow	0.0661
Polyurethane	0	Initial	0.0669
Polyurethane	1-2	JP-8	0.0711
Polyurethane	3-4	Tallow	0.0688
Polyurethane	5-6	JP-8	0.0710
Polyurethane	7-8	Tallow	0.0693
Teflon®	0	Initial	0.0711
Teflon®	1-2	JP-8	0.0713
Teflon®	3-4	Tallow	0.0711
Teflon®	5-6	JP-8	0.0714
Teflon®	7-8	Tallow	0.0714

Table B-8. Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Fluorosilicone	0	Initial	0.1344
Fluorosilicone	1-2	Diesel	0.1416
Fluorosilicone	3-4	Sasol IPK	0.1459
Fluorosilicone	5-6	Diesel	0.1427
Fluorosilicone	7-8	Sasol IPK	0.1465
Nitrile	0	Initial	0.1308
Nitrile	1-2	Diesel	0.1468
Nitrile	3-4	Sasol IPK	0.1424
Nitrile	5-6	Diesel	0.1456
Nitrile	7-8	Sasol IPK	0.1418
Viton®	0	Initial	0.1347
Viton®	1-2	Diesel	0.1353
Viton®	3-4	Sasol IPK	0.1370
Viton®	5-6	Diesel	0.1374
Viton®	7-8	Sasol IPK	0.1378
Polyurethane	0	Initial	0.1383
Polyurethane	1-2	Diesel	0.1909
Polyurethane	3-4	Sasol IPK	0.1816
Polyurethane	5-6	Diesel	0.1919
Polyurethane	7-8	Sasol IPK	0.1811
Teflon®	0	Initial	0.1412
Teflon®	1-2	Diesel	0.1411
Teflon®	3-4	Sasol IPK	0.1414
Teflon®	5-6	Diesel	0.1416
Teflon®	7-8	Sasol IPK	0.1415
Fluorosilicone	0	Initial	0.1337
Fluorosilicone	1-2	Diesel	0.1406
Fluorosilicone	3-4	R-8	0.1438
Fluorosilicone	5-6	Diesel	0.1411
Fluorosilicone	7-8	R-8	0.1439
Nitrile	0	Initial	0.1299
Nitrile	1-2	Diesel	0.1457
Nitrile	3-4	R-8	0.1408
Nitrile	5-6	Diesel	0.1440
Nitrile	7-8	R-8	0.1394

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Viton®	0	Initial	0.1349
Viton®	1-2	Diesel	0.1360
Viton®	3-4	R-8	0.1367
Viton®	5-6	Diesel	0.1375
Viton®	7-8	R-8	0.1376
Polyurethane	0	Initial	0.1365
Polyurethane	1-2	Diesel	0.1891
Polyurethane	3-4	R-8	0.1756
Polyurethane	5-6	Diesel	0.1901
Polyurethane	7-8	R-8	0.1752
Teflon®	0	Initial	0.1382
Teflon®	1-2	Diesel	0.1385
Teflon®	3-4	R-8	0.1387
Teflon®	5-6	Diesel	0.1388
Teflon®	7-8	R-8	0.1389
Fluorosilicone	0	Initial	0.1335
Fluorosilicone	1-2	Diesel	0.1422
Fluorosilicone	3-4	Rentech SPK	0.1445
Fluorosilicone	5-6	Diesel	0.1421
Fluorosilicone	7-8	Rentech SPK	0.1449
Nitrile	0	Initial	0.1300
Nitrile	1-2	Diesel	0.1459
Nitrile	3-4	Rentech SPK	0.1416
Nitrile	5-6	Diesel	0.1448
Nitrile	7-8	Rentech SPK	0.1398
Viton®	0	Initial	0.1355
Viton®	1-2	Diesel	0.1365
Viton®	3-4	Rentech SPK	0.1374
Viton®	5-6	Diesel	0.1378
Viton®	7-8	Rentech SPK	0.1378
Polyurethane	0	Initial	0.1380
Polyurethane	1-2	Diesel	0.1890
Polyurethane	3-4	Rentech SPK	0.1776
Polyurethane	5-6	Diesel	0.1910

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Polyurethane	7-8	Rentech SPK	0.1773
Teflon®	0	Initial	0.1400
Teflon®	1-2	Diesel	0.1395
Teflon®	3-4	Rentech SPK	0.1403
Teflon®	5-6	Diesel	0.1403
Teflon®	7-8	Rentech SPK	0.1404
Fluorosilicone	0	Initial	0.1354
Fluorosilicone	1-2	Diesel	0.1419
Fluorosilicone	3-4	Camelina	0.1461
Fluorosilicone	5-6	Diesel	0.1425
Fluorosilicone	7-8	Camelina	0.1457
Nitrile	0	Initial	0.1299
Nitrile	1-2	Diesel	0.1458
Nitrile	3-4	Camelina	0.1411
Nitrile	5-6	Diesel	0.1437
Nitrile	7-8	Camelina	0.1398
Viton®	0	Initial	0.1385
Viton®	1-2	Diesel	0.1391
Viton®	3-4	Camelina	0.1405
Viton®	5-6	Diesel	0.1406
Viton®	7-8	Camelina	0.1405
Polyurethane	0	Initial	0.1381
Polyurethane	1-2	Diesel	0.1896
Polyurethane	3-4	Camelina	0.1805
Polyurethane	5-6	Diesel	0.1883
Polyurethane	7-8	Camelina	0.1790
Teflon®	0	Initial	0.1397
Teflon®	1-2	Diesel	0.1395
Teflon®	3-4	Camelina	0.1399
Teflon®	5-6	Diesel	0.1401
Teflon®	7-8	Camelina	0.1397
Fluorosilicone	0	Initial	0.1350
Fluorosilicone	1-2	Diesel	0.1428
Fluorosilicone	3-4	Tallow	0.1458

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Fluorosilicone	5-6	Diesel	0.1431
Fluorosilicone	7-8	Tallow	0.1442
Nitrile	0	Initial	0.1315
Nitrile	1-2	Diesel	0.1486
Nitrile	3-4	Tallow	0.1430
Nitrile	5-6	Diesel	0.1457
Nitrile	7-8	Tallow	0.1412
Viton®	0	Initial	0.1342
Viton®	1-2	Diesel	0.1353
Viton®	3-4	Tallow	0.1369
Viton®	5-6	Diesel	0.1362
Viton®	7-8	Tallow	0.1369
Polyurethane	0	Initial	0.1367
Polyurethane	1-2	Diesel	0.1898
Polyurethane	3-4	Tallow	0.1751
Polyurethane	5-6	Diesel	0.1891
Polyurethane	7-8	Tallow	0.1741
Teflon®	0	Initial	0.1408
Teflon®	1-2	Diesel	0.1413
Teflon®	3-4	Tallow	0.1411
Teflon®	5-6	Diesel	0.1410
Teflon®	7-8	Tallow	0.1404
Fluorosilicone	0	Initial	0.1361
Fluorosilicone	1-2	JP-8	0.1478
Fluorosilicone	3-4	Sasol IPK	0.1474
Fluorosilicone	5-6	JP-8	0.1472
Fluorosilicone	7-8	Sasol IPK	0.1471
Nitrile	0	Initial	0.1282
Nitrile	1-2	JP-8	0.1450
Nitrile	3-4	Sasol IPK	0.1390
Nitrile	5-6	JP-8	0.1424
Nitrile	7-8	Sasol IPK	0.1370
Viton®	0	Initial	0.1342
Viton®	1-2	JP-8	0.1364

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Viton®	3-4	Sasol IPK	0.1358
Viton®	5-6	JP-8	0.1370
Viton®	7-8	Sasol IPK	0.1370
Polyurethane	0	Initial	0.1396
Polyurethane	1-2	JP-8	0.1985
Polyurethane	3-4	Sasol IPK	0.1815
Polyurethane	5-6	JP-8	0.1966
Polyurethane	7-8	Sasol IPK	0.1808
Teflon®	0	Initial	0.1406
Teflon®	1-2	JP-8	0.1402
Teflon®	3-4	Sasol IPK	0.1395
Teflon®	5-6	JP-8	0.1394
Teflon®	7-8	Sasol IPK	0.1401
Fluorosilicone	0	Initial	0.1364
Fluorosilicone	1-2	JP-8	0.1480
Fluorosilicone	3-4	R-8	0.1462
Fluorosilicone	5-6	JP-8	0.1457
Fluorosilicone	7-8	R-8	0.1453
Nitrile	0	Initial	0.1299
Nitrile	1-2	JP-8	0.1475
Nitrile	3-4	R-8	0.1384
Nitrile	5-6	JP-8	0.1441
Nitrile	7-8	R-8	0.1376
Viton®	0	Initial	0.1354
Viton®	1-2	JP-8	0.1379
Viton®	3-4	R-8	0.1380
Viton®	5-6	JP-8	0.1383
Viton®	7-8	R-8	0.1381
Polyurethane	0	Initial	0.1376
Polyurethane	1-2	JP-8	0.1960
Polyurethane	3-4	R-8	0.1754
Polyurethane	5-6	JP-8	0.1949
Polyurethane	7-8	R-8	0.1744
Teflon®	0	Initial	0.1411

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Teflon®	1-2	JP-8	0.1417
Teflon®	3-4	R-8	0.1407
Teflon®	5-6	JP-8	0.1402
Teflon®	7-8	R-8	0.1404
Fluorosilicone	0	Initial	0.1341
Fluorosilicone	1-2	JP-8	0.1456
Fluorosilicone	3-4	Rentech SPK	0.1437
Fluorosilicone	5-6	JP-8	0.1433
Fluorosilicone	7-8	Rentech SPK	0.1437
Nitrile	0	Initial	0.1310
Nitrile	1-2	JP-8	0.1486
Nitrile	3-4	Rentech SPK	0.1407
Nitrile	5-6	JP-8	0.1452
Nitrile	7-8	Rentech SPK	0.1390
Viton®	0	Initial	0.1361
Viton®	1-2	JP-8	0.1385
Viton®	3-4	Rentech SPK	0.1389
Viton®	5-6	JP-8	0.1393
Viton®	7-8	Rentech SPK	0.1394
Polyurethane	0	Initial	0.1360
Polyurethane	1-2	JP-8	0.1932
Polyurethane	3-4	Rentech SPK	0.1733
Polyurethane	5-6	JP-8	0.1911
Polyurethane	7-8	Rentech SPK	0.1723
Teflon®	0	Initial	0.1400
Teflon®	1-2	JP-8	0.1401
Teflon®	3-4	Rentech SPK	0.1398
Teflon®	5-6	JP-8	0.1388
Teflon®	7-8	Rentech SPK	0.1394
Fluorosilicone	0	Initial	0.1354
Fluorosilicone	1-2	JP-8	0.1467
Fluorosilicone	3-4	Camelina	0.1448
Fluorosilicone	5-6	JP-8	0.1476
Fluorosilicone	7-8	Camelina	0.1466

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Nitrile	0	Initial	0.1302
Nitrile	1-2	JP-8	0.1476
Nitrile	3-4	Camelina	0.1396
Nitrile	5-6	JP-8	0.1455
Nitrile	7-8	Camelina	0.1389
Viton®	0	Initial	0.1360
Viton®	1-2	JP-8	0.1394
Viton®	3-4	Camelina	0.1383
Viton®	5-6	JP-8	0.1398
Viton®	7-8	Camelina	0.1395
Polyurethane	0	Initial	0.1384
Polyurethane	1-2	JP-8	0.1976
Polyurethane	3-4	Camelina	0.1777
Polyurethane	5-6	JP-8	0.1965
Polyurethane	7-8	Camelina	0.1781
Teflon®	0	Initial	0.1397
Teflon®	1-2	JP-8	0.1404
Teflon®	3-4	Camelina	0.1397
Teflon®	5-6	JP-8	0.1403
Teflon®	7-8	Camelina	0.1401
Fluorosilicone	0	Initial	0.1344
Fluorosilicone	1-2	JP-8	0.1468
Fluorosilicone	3-4	Tallow	0.1439
Fluorosilicone	5-6	JP-8	0.1460
Fluorosilicone	7-8	Tallow	0.1445
Nitrile	0	Initial	0.1315
Nitrile	1-2	JP-8	0.1497
Nitrile	3-4	Tallow	0.1405
Nitrile	5-6	JP-8	0.1471
Nitrile	7-8	Tallow	0.1399
Viton®	0	Initial	0.1362
Viton®	1-2	JP-8	0.1393
Viton®	3-4	Tallow	0.1389
Viton®	5-6	JP-8	0.1400

Table B-8 (Cont'd). Volume Data for Switch Loading Samples

Material	Weeks	Fuel	Avg. Volume (mL)
Viton®	7-8	Tallow	0.1400
Polyurethane	0	Initial	0.1385
Polyurethane	1-2	JP-8	0.1967
Polyurethane	3-4	Tallow	0.1754
Polyurethane	5-6	JP-8	0.1952
Polyurethane	7-8	Tallow	0.1758
Teflon®	0	Initial	0.1387
Teflon®	1-2	JP-8	0.1404
Teflon®	3-4	Tallow	0.1395
Teflon®	5-6	JP-8	0.1394
Teflon®	7-8	Tallow	0.1391

Table B-9. Tensile Strength Data for Switch Loading Samples

Material	Fuel Pair	Tensile Strength (psi)	Avg Tensile Strength (psi)
Fluorosilicone	Diesel / Sasol IPK	695	770
		823	
		793	
Nitrile	Diesel / Sasol IPK	2312	2321
		2479	
		2173	
Viton®	Diesel / Sasol IPK	2265	2225
		2198	
		2210	
Polyurethane	Diesel / Sasol IPK	1481	1449
		1498	
		1368	
Teflon®	Diesel / Sasol IPK	2859	3099
		3114	
		3325	
Fluorosilicone	Diesel / R-8	739	709
		693	
		695	
Nitrile	Diesel / R-8	1996	2266
		2263	
		2539	
Viton®	Diesel / R-8	2089	2038
		1968	
		2057	
Polyurethane	Diesel / R-8	1271	1232
		1232	
		1194	
Teflon®	Diesel / R-8	2657	2748
		2748	
		2837	
Fluorosilicone	Diesel / Rentech SPK	857	793
		794	
		729	
Nitrile	Diesel / Rentech SPK	1855	1866
		1386	
		2358	
Viton®	Diesel / Rentech SPK	2036	2087
		2117	
		2107	
Polyurethane	Diesel / Rentech SPK	1175	1403
		1571	
		1463	

Table B-9 (Cont'd). Tensile Strength Data for Switch Loading Samples

Material	Fuel Pair	Tensile Strength (psi)	Avg Tensile Strength (psi)
Teflon®	Diesel / Rentech SPK	2060	2187
		2298	
		2202	
Fluorosilicone	Diesel / Camelina	556	507
		722	
		242	
Nitrile	Diesel / Camelina	2292	2312
		2014	
		2332	
Viton®	Diesel / Camelina	2025	2053
		2091	
		2043	
Polyurethane	Diesel / Camelina	824	1054
		1159	
		1180	
Teflon®	Diesel / Camelina	2351	2368
		2382	
		2370	
Fluorosilicone	Diesel / Tallow	742	749
		709	
		797	
Nitrile	Diesel / Tallow	2380	2196
		1932	
		2276	
Viton®	Diesel / Tallow	1984	1972
		1995	
		1939	
Polyurethane	Diesel / Tallow	1689	1667
		1429	
		1882	
Teflon®	Diesel / Tallow	2525	2510
		2516	
		2488	
Fluorosilicone	JP-8 / Sasol IPK	749	705
		655	
		710	
Nitrile	JP-8 / Sasol IPK	2292	1817
		2420	
		738	
Viton®	JP-8 / Sasol IPK	2125	2035
		1960	
		2021	

Table B-9 (Cont'd). Tensile Strength Data for Switch Loading Samples

Material	Fuel Pair	Tensile Strength (psi)	Avg Tensile Strength (psi)
Polyurethane	JP-8 / Sasol IPK	1389	1251
		1111	
		1253	
Teflon®	JP-8 / Sasol IPK	2283	2506
		2507	
		2729	
Fluorosilicone	JP-8 / R-8	728	677
		734	
		568	
Nitrile	JP-8 / R-8	2112	2348
		2425	
		2506	
Viton®	JP-8 / R-8	2162	2063
		1979	
		2049	
Polyurethane	JP-8 / R-8	1525	1450
		1111	
		1715	
Teflon®	JP-8 / R-8	2703	2771
		2793	
		2818	
Fluorosilicone	JP-8 / Rentech SPK	710	744
		730	
		792	
Nitrile	JP-8 / Rentech SPK	2325	2109
		2270	
		1733	
Viton®	JP-8 / Rentech SPK	2144	1999
		1857	
		1997	
Polyurethane	JP-8 / Rentech SPK	1452	1376
		1314	
		1364	
Teflon®	JP-8 / Rentech SPK	2457	2712
		2864	
		2817	
Fluorosilicone	JP-8 / Camelina	741	693
		751	
		587	
Nitrile	JP-8 / Camelina	2402	2363
		2307	
		2381	

Table B-9 (Cont'd). Tensile Strength Data for Switch Loading Samples

Material	Fuel Pair	Tensile Strength (psi)	Avg Tensile Strength (psi)
Viton®	JP-8 / Camelina	2151	2065
		1815	
		2228	
Polyurethane	JP-8 / Camelina	1696	1426
		1319	
		1263	
Teflon®	JP-8 / Camelina	3295	2904
		2606	
		2812	
Fluorosilicone	JP-8 / Tallow	708	763
		799	
		782	
Nitrile	JP-8 / Tallow	2450	2368
		2256	
		2399	
Viton®	JP-8 / Tallow	2099	1994
		2073	
		1810	
Polyurethane	JP-8 / Tallow	810	1086
		1178	
		1271	
Teflon®	JP-8 / Tallow	2670	2623
		2585	
		2613	

Table B-10. Tensile Strength Data for Baseline O-rings

Material	Tensile Strength (psi)	Avg Tensile Strength (psi)
Fluorosilicone	934	981
	1007	
	1001	
Nitrile	3054	3026
	2947	
	3076	
Viton®	2681	2369
	1889	
	2537	
Polyurethane	3151	3029
	2820	
	3115	
Teflon®	3086	3064
	3062	
	3045	
Viton®	2758	2646
	2571	
	2610	